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RIVER BOD ABNORMALITIES: A CASE STUDY APPROACH. THE CLINTON RIVER BELOW PONTIAC, MICHIGAN. THE TITTABAWASSEE RIVER BELOW MIDLAND, MICHIGAN

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SCHOOL OF PUBLIC HEALTH
DEPARTMENT OF ENVIRONMENTAL HEALTH

Final Report

RIVER BOD ABNORMALITIES

A Case Study Approach

The Clinton River Below Pontiac, Michigan
The Tittabawassee River Below Midland, Michigan

JOHN J. GANNON
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The Tittabawassee River below Midland, Michigan

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SECTION I

SUMMARY AND CONCLUSIONS

As a convenience, summaries and conclusions are presented by section, followed by a final section on suggested areas of additional work.

Section II - Introduction

The main objective of this study has been to investigate river BOD abnormalities, limiting consideration, however, to the effect of the BOD rate. The major hypothesis tested has been that where excessive river BOD removals are observed, i.e., where k_r is higher than expected from a knowledge of the waste oxidation rate and time of passage, the cause is not due to an increased oxidation rate in the river, but rather due to some abnormality such as sludge deposition or biological extraction and accumulation. The focus, therefore, has been on the river situation with the laboratory activity assuming a supporting role.

For purposes of testing the major hypothesis, two case studies were selected for intensive study, the first involving a municipal waste discharging from the Pontiac waste treatment plant into the Clinton River and covering the river section from Pontiac to Rochester, and the second involving an industrial waste from the Dow Chemical Company waste treatment plant discharging into the Tittabawassee River and covering the river section from Midland to Saginaw.

Section III - Clinton River

An intensive around the clock survey has been conducted on the Clinton River for the period August 23-25, 1960 and this, in turn was supplemented by additional survey work under similar conditions on July 12, 1961. BOD removal rates in the river were high with a k_r of approximately 1.1, while the k_1 rate calculated by working backward from river D.O. and BOD data was in the range of 0.06 to 0.1, and the k_1 rate obtained from laboratory studies on river water samples was in the range of 0.01 or less. Extensive contact opportunity exists between the river water and (1) the channel bottom and sides, (2) numerous obstructions caused by fallen trees and limbs, and (3) abundant aquatic vegetation that completely fills the channel in some sections. Microscopic examination of specimens collected from these obstructions indicated the presence of a slime film suggesting the strong possibility of biological extraction and accumulation. On the other hand, it has been demonstrated in the laboratory that BOD rates conducted under continuous mixing are higher than those conducted under the usual quiescent conditions. Thus, the conclusion is drawn that mixing does have an influence on the k rate, suggesting that the higher river $k_r = 1.1$ might be due to a combination of biological extraction and accumulation and certain other natural conditions such as turbulence which have accelerated the BOD reaction. In addition, the assumption is made that low laboratory k_1 rates of 0.01 or less, have been due, among other things, to the influence of nitrification toward the end of the standard 5-day incubation period, thereby causing low k_1 values where the conventional monomolecular computational methods of analysis are employed.

As a result of the information collected on the Clinton River, no firm acceptance or rejection of the major hypothesis of the study can be made. To the degree that an increased oxidation rate is present in the river, the hypothesis is rejected, but, inasmuch as there is a strong suggestion of biological extraction and accumulation, and since it has not been possible to assess the relative influence of each factor, no firm conclusion can be drawn.

Section IV - Tittabawassee River

As with the Clinton River, an intensive around the clock survey was conducted on August 23-25, 1961 on the Tittabawassee River for the section from Midland to Saginaw. BOD removal rates in the river were high with a k_r of approximately 0.2, while the k_1 of the river and effluent samples were of the order of approximately 0.02. Of the measurements taken, the dissolved oxygen concentrations were the most sensitive, followed by routine river 5-day BOD determinations, and the special rate studies in this order.

No strong evidence became available either in the field or the laboratory to support the major hypothesis of the study, and it appears more logical to assume that BOD reduction between sampling stations along the Tittabawassee River was due to an increased oxidation rate in the river over that developed under standard laboratory conditions.

Section V - BOD Rate Summaries

In support of the intensive river water quality surveys conducted on both the Clinton and Tittabawassee Rivers, a large number of BOD rate studies were conducted on both effluent samples and selected river water samples to reflect seasonal variation, temperature variation, mixing vs. non-mixing, and the influence of carrying on rate studies for extended periods of one to three months. During the period of this investigation, some 208 BOD rates were run on Clinton River water and Pontiac waste treatment plant effluents, together with 139 BOD rates on Tittabawassee River water and Dow waste treatment plant effluent, making a total of 347 rates.

In the case of the Clinton River, the most noticeable differences appeared in the mixing vs. non-mixing category, with no conclusive variation demonstrated on a seasonal or temperature basis. Also, the long term rates indicated no complete stabilization in terms of oxygen demand, even in the case of the sample incubated for 166 days.

As far as the Tittabawassee River is concerned, it has not been possible to demonstrate BOD k_1 rate differences on either a seasonal, temperature, or mixing basis. Also, as with the long term Clinton River rates, no complete stabilization in terms of oxygen demand was demonstrated even for the rate which was run for 164 days.

Section VI - BOD Procedures

Major reliance in this project has been placed on the reaeration procedure for conducting BOD rate studies as proposed by Elmore of the T.V.A. staff. A discussion of the method has been presented, including the results of replication tests conducted on both Clinton River and Tittabawassee River water which suggest that the procedures employed by both this group and Elmore are the same.

A comparison of reaeration and dilution BOD results has been presented, indicating that in the case of Tittabawassee River water the dilution procedure gave consistently higher results, while no significant difference could be shown for the Clinton River samples.

Another factor considered has been the influence of continuous mixing on BOD results, where it was demonstrated that mixing definitely increased both BOD level and rate in the case of the Clinton River, but increased only the BOD level in the case of Tittabawassee samples. For the Tittabawassee River samples it has been indicated that dilution definitely has a statistically significant influence on standard 5-day BOD level, but this could not be demonstrated for Clinton River data.

Limited studies were conducted to evaluate the influence of BOD incubation under light and dark conditions, where it was shown that oxygen was produced rather than utilized as a result of photosynthetic activity by the algae in the river water. Also evaluated was the influence of settling and filtering samples before running BOD rates, where very little difference was demonstrated except in the case of the Pontiac activated sludge effluent collected on July 17, 1962. Here, settling and filtering definitely decreased the BOD level over the non-settled sample.

As an aid in interpretation of BOD rate information, it was decided early in 1961 to attempt to evaluate the degree of nitrification occurring during the course of routine rate studies by measuring the concentration of NH_3, NO_2, and NO_3 at the beginning, the mid-point, and end of every routine BOD rate study. This data has been a great help in interpreting the BOD information, and showed that nitrification has been a definite influence on the BOD rate studies conducted on the Clinton River samples, but not on the Tittabawassee River samples.

Chlorination of the Pontiac waste treatment plant effluent caused a chlorine residual to persist in the Clinton River as far downstream as the Grand Trunk railroad bridge during low flow periods. Limited BOD rate studies conducted on chlorinated and dechlorinated samples suggested that chlorine might have functioned as a retarding and oxidizing agent in terms of BOD influences, rather than as a sterilizing agent.

Efforts toward the development of a continuous recording BOD apparatus are reported involving a galvanic cell oxygen analyzer sealed in a respirometer cell. The apparatus is currently under development and should be operational in the near future.

Also, consideration has been given to dissolved oxygen procedures including a comparison among analysts using the Winkler method, a comparison of polarographic and Winkler D.O. results for both the Clinton River and Tittabawassee River water samples, and a discussion of applications of the galvanic cell oxygen analyzer.

Section VII - Comparison of Mathematical and Graphical Evaluation of k_1

Several published mathematical and graphical procedures for the evaluation of the BOD velocity constant have been considered, assuming in each case that the monomolecular or first order reaction applied. In addition, comparisons have been presented of the results obtained by applying each method to the same rate studies conducted on selected samples from both the Clinton and Tittabawassee Rivers, showing that the method of mathematical analysis definitely influences the resulting k_1 value.

It has been recommended that a first step in the analysis of BOD rate information should be a linear plot of BOD versus time for the evaluation of any abnormalities. Following this, it appears that a combination of the Lee grid and "moments" method gives the best results for the effort expended; if a high speed computer is available, the Reed-Theriault program would be recommended.

Section VIII - Time of Passage Determination in Inland Streams

Time of passage information assumed particular importance in this project because of specific interest in the river BOD removal rate k_r, which is determined from 5-day BOD samples taken at river sampling stations together with the time of travel between these sampling stations. As a result, efforts were directed toward the determination of adequate time information for both the Clinton River and Tittabawassee River.

Results have been presented of time of passage determinations using the displacement method of calculation for both the Clinton and Tittabawassee Rivers under runoff conditions prevailing during the respective intensive water quality surveys in 1960 and 1961. In addition, comparisons have been made for the Tittabawassee River between results obtained using the displacement method with time determined using the external tracer Rhodamine B and an internal chloride tracer. Generally times were comparable among the methods as far as Freeland, with more divergence further downstream.

Section IX - Aeration at Two Waste Treatment Plant Outfall Structures

During the early phases of this project, it was discovered that the open outfall structures of both the Pontiac waste treatment plant and the Dow Chemical Company waste treatment plant caused a definite oxygen pickup by the effluent. As a result, special surveys were conducted on July 12, 1961 at Pontiac and August 1, 1962 at Dow to more fully document the earlier findings. These results have been presented, and comparisons have been made between the observed and predicted results, using equations developed by British workers studying aeration at weir systems, indicating good agreement in the case of Pontiac, but indicating predictions of the order of 13 to 14 per cent higher than the observed results in the case of Dow.

Section X -Programming River Dissolved Oxygen Calculations

A method for programming river dissolved oxygen calculations on a high speed digital computer has been presented employing the approach proposed by Velz. Time and cost figures are given for the Clinton River calculations, indicating considerable savings in technical labor and, no doubt, increasing the reliability of the results because of reduction in the possibility of human error.

Section XI - River Biological Surveys

To supplement the chemical and biochemical data collected during this investigation, several biological surveys were conducted on the Clinton and Tittabawassee Rivers. Biological results from both rivers failed to show any specific organism present in overwhelming numbers, nor were there any extensive sludge deposits observed in either river. As previously indicated for the Clinton River, excellent contact opportunity exists between the river water and various weeds, tree limbs, rocks, etc. with attached slime, suggesting that part of the BOD removal is due to biological extraction and accumulation.

Section XII - BOD Literature Review

Much has been written on the BOD test and in recent years considerable laboratory work has been done on the characteristics of specific wastes. A review of the BOD literature has been presented in two parts: a) the BOD test, and b) River BOD Abnormalities.

Suggested Areas of Additional Work

Several areas of additional work are suggested as a result of the findings of this study. First, it is apparent that no adequate explanation is available to account for the differences between the laboratory k_l and the river k_r. This, no doubt, is partially due to inadequacies of the existing BOD techniques. Probably it may never be possible to develop a BOD procedure in the laboratory that will duplicate the natural river conditions, but certainly efforts should be directed toward improving existing procedures. The development of a continuous recording BOD apparatus is encouraging in providing more detailed data than has ever been previously available, and should be useful in further studies on the influence on the BOD test of such things as nitrification, light and dark incubation, algae, mixing, etc.

In addition to improvement of the laboratory BOD test it appears that much useful fundamental information could be obtained about BOD removal rates from controlled studies using artificial channels. This approach then, would be somewhere between the natural stream conditions and the highly artificial laboratory bottle methods. Many variables could be investigated such as nutrient type and level, degree of turbulence, influence of sludge depositions, etc. Artificial channels, which could be used for such studies, are under design at the present time in connection with another project, but it is anticipated they will be available in the future for studies on this subject.

A third area of future investigation should be aimed at the development of a more appropriate mathematical model than the monomolecular relationship to describe the BOD progression. This is especially true if an S type curve develops, where the monomolecular relationship generally gives a very poor fit.

SECTION II

INTRODUCTION

The main objective of this study has been to investigate river BOD abnormalities, limiting consideration, however, to the effect of the BOD rate. The early work of Streeter and Phelps indicated that for the Ohio River the monomolecular equation generally expressed the biochemical oxygen demand along the river, with the rate constant k_1 having a statistical average of 0.1 at 20°C. However, since that time, the writer and other investigators have observed different BOD reduction rates due to the abnormalities of sludge deposition, biological extraction and accumulation, and, also possibly due to other factors.

In this study a distinction has been made between the biochemical reaction rate k_1 of laboratory studies, and the river reduction rate k_r which is determined from 5-day BOD samples taken at river sampling stations, and from a knowledge of the time of passage between sampling stations. In other words, the river k_r is composed of, not only the normal oxidation rate of the wastes expressed in terms of the laboratory k_1 but, also, includes any additional BOD removal which might be caused by sludge deposition, or biological extraction and accumulation, or accelerated oxidation in the river. Sludge deposition is the natural counterpart of treatment plant settling, while biological extraction and accumulation is the natural counterpart of either the trickling filter or activated sludge treatment processes, depending on whether the extraction is caused by growths attached to the stream bottom or by biological floc dispersed in the stream flow.

The major hypothesis tested in this study is that where excessive river BOD removals are observed, i.e., where k_r is higher than expected from a knowledge of the waste oxidation rate and time of passage, the cause is not due to an increased oxidation rate in the river, but rather due to some abnormality such as sludge deposition or biological extraction and accumulation. The focus, therefore, has been on the river situation with the laboratory activity assuming a supporting role.

For purposes of testing the major hypothesis, two case studies were selected for intensive study, one involving a municipal waste and the second involving an industrial waste. Several Michigan streams were screened, including the Clinton, Flint, Tittabawassee, Kalamazoo, and Paw Paw, before final decision was made to investigate the Clinton River from Pontiac to Rochester, and the Tittabawassee River below the Dow Chemical Company from Midland to Saginaw. Several factors entered into the decision to select these rivers including background information on water quality indicating a high river k_r, detailed river channel cross section information, a single major waste source in each case, adequate stream gaging by U.S.G.S. in the critical section of the river, and finally, the cooperation of the staff of the Pontiac waste treatment plant and the waste control group of the Dow Chemical Company. Additional detailed information will be presented later in this report under the sections devoted to each of the selected rivers.

In terms of specific procedures, the investigation was planned along the lines of running at least one intensive water quality survey on each river, under steady state conditions of runoff and loading during the warm weather summer period. In addition, a number of river and plant effluent samples were collected for BOD rate analysis to reflect seasonal variation, temperature variation, mixing vs. non-mixing conditions, and the influence of long term incubation.

One of the original aims accomplished has been an evaluation of the effect of the type of mathematical analysis on the resulting k_1 value for the monomolecular equation and, also, to question whether or not the monomolecular equation does describe the BOD progression.

As the study progressed, additional areas of investigation not originally planned presented themselves, including river time of passage determination using Rhodamine B dye tracer, oxygen increase through a treatment plant outfall, programming river dissolved oxygen calculations on high speed computers, application of newly developed electrodes for dissolved oxygen determination, evaluation of the influence of nitrification in the BOD rates of both the Clinton and Tittabawassee, and improvement of the BOD procedure for rate studies.

It is recognized that by virtue of certain varying waste and hydrologic characteristics the same degree of control has not been possible as might have been achieved with a standard laboratory situation. However, it is felt that the need exists to relate resulting stream conditions to the waste characteristics involved. Many recent laboratory studies have been reported on the BOD characteristics of specific wastes but rarely, if at all, have they been related to the subsequent stream conditions. There is little information available, therefore, to indicate whether these rates do in effect hold for the receiving streams.

SECTION III

CLINTON RIVER

The first case study selected for intensive investigation consisted of the Clinton River between Pontiac and Rochester, Michigan. Various factors entered into the selection of this river, including previous water quality data indicating a river k_r higher than normal, a river channel with no major tributaries entering the selected section, all of the waste entering the river at the beginning of the critical section or brought from upstream sources, the major waste source consisting of treated effluent from the Pontiac waste treatment plant, the active cooperation of the staff of the Pontiac plant, and finally the relative accessibility of the study area, involving a distance of about 45 miles from Ann Arbor to Pontiac.

This section of the report presents background information on the Clinton River, including the results of analysis of the river drought flows at Mount Clemens and at Auburn Heights. In addition, an extensive discussion is presented of the August, 1960 intensive river water quality survey covering the pollution sources and magnitudes, the sampling program, the river runoff and channel characteristics, and the river dissolved oxygen and BOD relationships. In order to collect additional information, a limited water quality survey was conducted in July 1961, and the results of the chlorine residual determinations made during this survey will be presented and discussed.

Basin Description

The Clinton River Basin (Figure 3-1), with a drainage area of approximately 741 square miles, lies south of the thumb area of the Lower Peninsula and discharges into Lake St. Clair near Mount Clemens. It comprises parts of St. Clair, Lapeer, Macomb, and Oakland counties. The Clinton River Basin is bounded on the south by the City of Detroit, with the resulting suburban expansion into the southern part of the basin. In contrast, the northern part is essentially rural in nature providing extreme variation between the two parts of the basin.

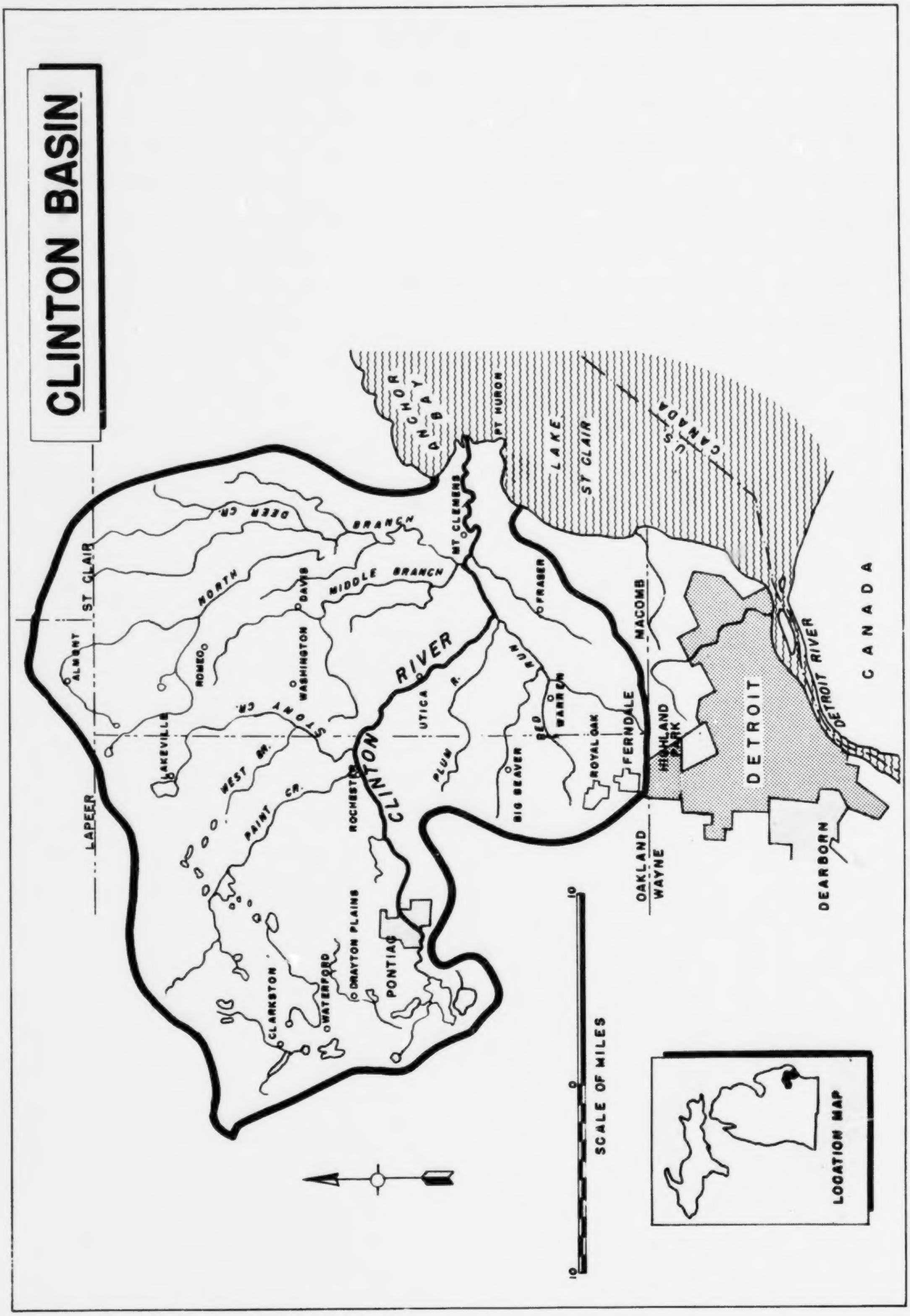
CLINTON BASIN
LAPEER
ST CLAIR
ALMONT
LAKEVILLE
ROMEO
WASHINGTON
DAVIS
NORTH BRANCH
DEER CR.
MIDDLE BRANCH
MT CLEMENS
ANCHOR BAY
PT HURON
LAKE ST CLAIR
U.S.
CANADA
STONY CR.
WEST BR.
PAINT CR.
ROCHESTER
CLINTON RIVER
UTICA
PLUM R.
FRASER
RED RUN
WARREN
BIG BEAVER
ROYAL OAK
FERNDALE
MACOMB
OAKLAND
WAYNE
HIGHLAND PARK
DETROIT
DETROIT RIVER
CANADA
DEARBORN
CLARKSTON
WATERFORD
DRAYTON PLAINS
PONTIAC
SCALE OF MILES
10
0
10
LOCATION MAP

Figure 3-1

The section of the river under study extends from Pontiac to Rochester, which is seen to be in the headwaters of the basin. Also, several lake areas are seen above Pontiac which tend to regulate the stream flow especially during the dry part of the year. A U.S.G.S. stream gage located at Auburn Heights, downstream from Pontiac, is reported to have a tributary drainage area of 123 square miles.

The major population concentration in the study area is centered in and around Pontiac, with the 1960 population for the city reported as 82,233 compared to 73,112 reported in 1950. Major employment is at the Pontiac Division of theGeneral Motors Corporation located in Pontiac.

Others have presented more detailed reports on various phases of the water resources in the Clinton River Basin including the efforts of the Michigan Water Resources Commission.(1)(2)

Drought Flows

As a frame of reference for discussion of water quality data collected under low flow conditions, drought flows are presented, first, for the Clinton River at Mount Clemens gage in Table 3-1, and, second, for the Clinton River at Auburn Heights gage in Table 3-2. The drought flows for the Clinton River at Mount Clemens gage are an extension from 1954 to 1960 of the original figures published by Velz and Gannon,(3) while the Clinton River at Auburn Heights flows have been developed from correlations between the Mount Clemens and Auburn Height flows. This approach was necessary because the Auburn Heights gage was established in 1956 and, therefore, did not have a sufficiently long record for probability analysis. Inasmuch as the correlations were developed for the 30-day average flow, this is the only time period presented for the Auburn Heights gage. Because of influence on the river flow above Auburn Heights by discharge from the Pontiac waste treatment plant, these correlations cannot be applied to shorter drought durations.

TABLE 3-1

DROUGHT FLOWS IN CFS

Clinton River at Mount Clements

Frequency of Occurrence	1 Day	7 Days	15 Days	30 Days
Most Probable	87.5	98.0	103.0	115.0
1 in 5 Years	46.6	55.5	61.0	68.5
1 in 10 Years	34.0	41.6	46.0	53.0
1 in 20 Years	25.4	31.3	35.4	41.3

TABLE 3-2

DROUGHT FLOWS IN CFS

Clinton River at Auburn Heights

Frequency of Occurrence	30 Days
Most Probable	46.9
1 in 5 Years	41.7
1 in 10 Years	40.0
1 in 20 Years	38.6

AUGUST, 1960 WATER QUALITY SURVEY

For purposes of testing the major hypothesis of the project, a special water quality survey was conducted through the critical section of the river under normal low flow and pollution loading conditions during the period August 23-25, 1960. Previous water quality data collected by the Michigan Water Resources Commission(2) proved invaluable in the design of this survey.

Pollution Sources and Magnitudes

All of the major pollution sources influencing water quality in the critical section of the Clinton extending from Pontiac to Rochester come either from the Pontiac waste treatment plant or are brought to this section from upstream sources. Thus, determination of the pollution load at the beginning of the section provides an excellent starting point for any theoretical river analysis.

Figure 3-2 is a flow diagram of the waste treatment facilities of the City of Pontiac where it is seen that complete biological treatment is given to the waste, either by means of trickling filter or activated sludge units which operate in parallel. There is some variation in the flow between the two units, with approximately 50 to 60 per cent of the total flow going through the activated sludge units, and 40 to 50 per cent of the flow going through the trickling filter units. It should be reported that construction started in the summer of 1961 on an addition to the plant consisting of activated sludge units, with the expectation that the use of the old trickling filter units would be discontinued when the new units became available.

Inasmuch as the Pontiac waste treatment plant staff run 5-day BOD determinations on 24-hour composite samples of the effluent from both the trickling filter and activated sludge units on a daily basis, it was not felt necessary to duplicate their efforts during the intensive survey period. Because of personnel limitations, no rate studies were conducted on the plant effluent during the survey, and reliance has been placed on such studies conducted at other times during the summers of 1960 and 1961.

In addition to the plant discharges, organic loadings in the river from upstream sources were evaluated by river samples collected from a bridge just above the plant as part of the routine river sampling program. This station is indicated as station 1 on Figure 3-3.

Table 3-3 is a summary of the organic BOD load conditions both from the Pontiac waste treatment and upstream sources as reflected at river sampling station 1. Plant flows were reported by the staff of the Pontiac plant, while the river flow was estimated from flow information obtained from the official U.S.G.S. gage at Auburn Heights.

River Sampling Program

In order to collect the necessary water quality data, a river sampling program was designed to routinely collect samples

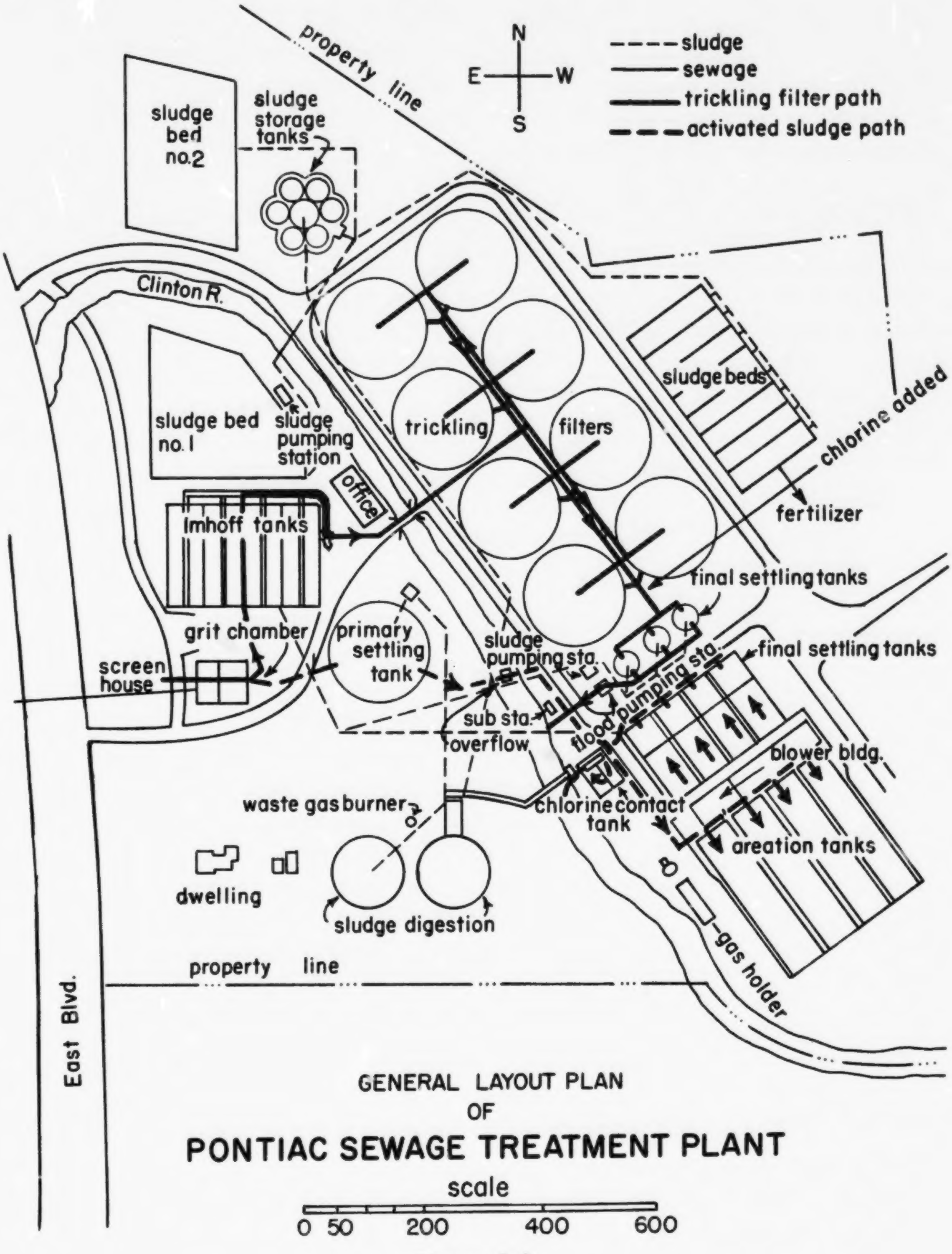
N
E
W
S
sludge
sewage
trickling filter path
activated sludge path
property line
sludge bed no.2
sludge storage tanks
Clinton R.
sludge bed no. 1
sludge pumping station
office
trickling
filters
sludge beds
chlorine added
fertilizer
Imhoff tanks
final settling tanks
grit chamber
primary settling tank
sludge pumping sta.
final settling tanks
screen house
pumping sta.
sub sta.
flood
overflow
blower bldg.
waste gas burner
chlorine contact tank
areation tanks
dwelling
sludge digestion
gas holder
property line
East Blvd.
GENERAL LAYOUT PLAN
OF
PONTIAC SEWAGE TREATMENT PLANT
scale
0 50 200 400 600

Figure 3-2

from 8 river sampling stations, every 4 hours, day and night, over a 48-hour period, making a total of 96 routine samples. The stations are indicated by number on Figure 3-3. In addition, 5 daytime runs were made to station 9 located at Yates Mill bridge below Rochester.

TABLE 3-3

MEASUREMENTS ON WASTE SOURCES AND SELECTED RIVER LOCATIONS IN VICINITY OF PONTIAC DURING SURVEY PERIOD

Location	BOD_5	Flow	BOD_5 lbs/day
Clinton River at bridge upstream from Plant (Station 1)	3.25 mg/l*	15.3 cfs	268.1
Pontiac Waste Treatment Plant - Trickling Filter			
Aug. 22, 1960	43 mg/l**	4.6 MGD	1649
Aug. 23, 1960	43 mg/l**	4.5 MGD	1614
Aug. 24, 1960	20 mg/l**	4.6 MGD	767
Average			1343
Pontiac Waste Treatment Plant - Activated Sludge			
Aug. 22, 1960	30 mg/l**	6.5 MGD	1626
Aug. 23, 1960	19 mg/l**	6.4 MGD	1014
Aug. 24, 1960	26 mg/l**	6.3 MGD	1366
Average			1335

*Mean of Period

**Reported by Plant Operator

Routine analysis of each sample consisted of temperature, D.O., and BOD_5, with the last test run in two dilutions. Also, pH determinations were made on samples collected at stations 1, 2 and 5. The results of the survey are presented in detail in Appendix I-A of this report. Each sampling run took approximately four hours, with sample collection starting at station 1 above the Pontiac waste treatment plant and ending at station 8 above Rochester. From here the samples were taken immediately to a temporary laboratory established at the Rochester waste treatment

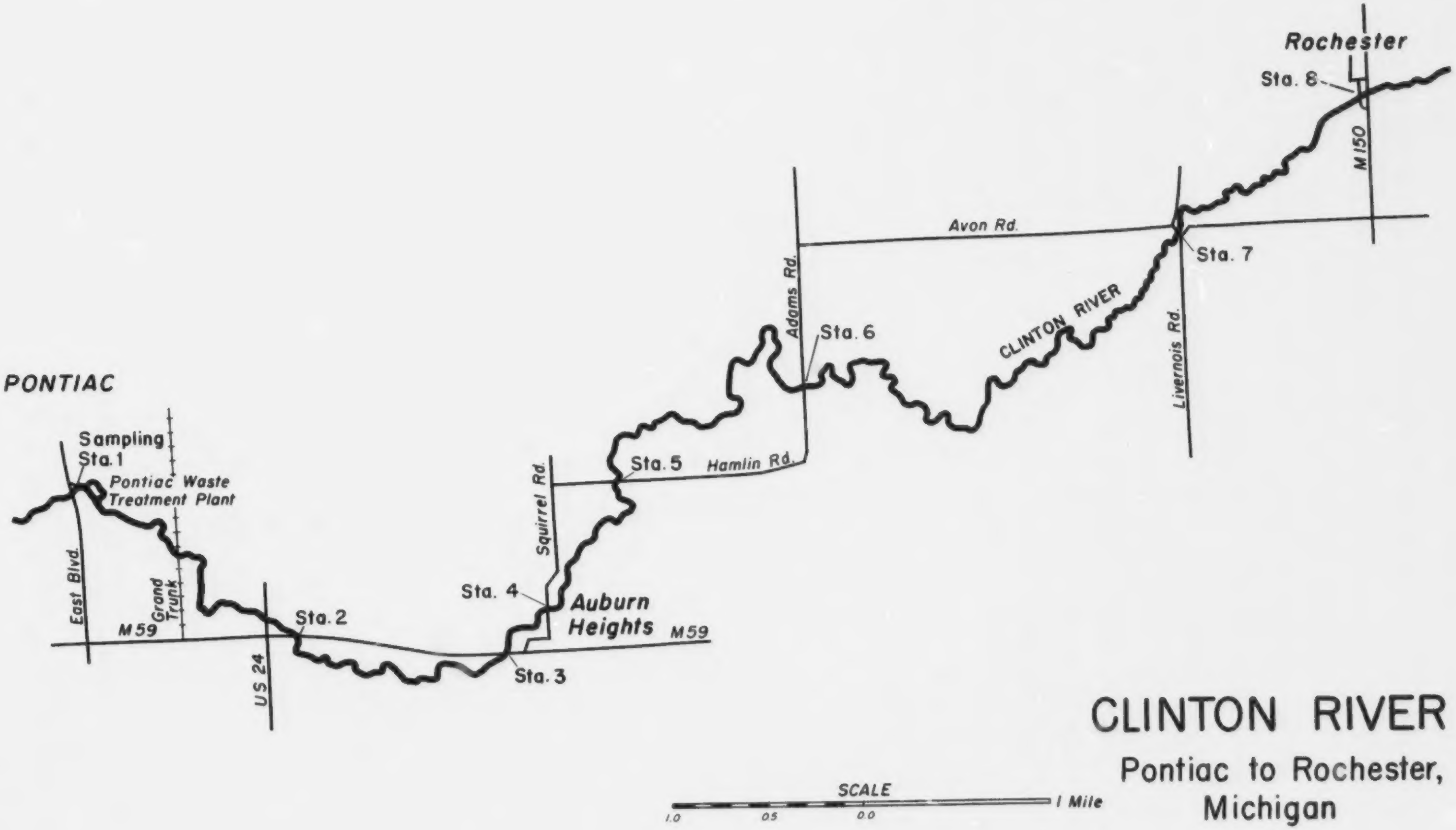
CLINTON RIVER
Pontiac to Rochester,
Michigan
PONTIAC
Sampling
Sta. 1
Pontiac Waste
Treatment Plant
East Blvd.
Grand
Trunk
M59
US 24
Sta. 2
Sta. 3
Sta. 4
Auburn
Heights
M59
Squirrel Rd.
Sta. 5
Hamlin Rd.
Adams Rd.
Sta. 6
Avon Rd.
CLINTON RIVER
Livernois Rd.
Sta. 7
Rochester
Sta. 8
M150
SCALE
1.0
0.5
0.0
1 Mile

Figure 3-3

plant, where all the analyses were completed as soon as possible in accordance with the procedures recommended in the 11th Edition of Standard Methods.(4) Dissolved oxygen samples were fixed in the field at the time of collection, with the final titrations completed in the laboratory at the end of each run. BOD samples were incubated in a basement room of the Rochester waste treatment plant, where the temperature remained constant at 20° C. during the survey period, and were then transported back to the School of Public Health laboratories and incubated at 20° C. for the remainder of the 5-day period before completion of the test. Regular sampling personnel of the Pontiac waste treatment plant staff were employed during their off duty hours to collect the river samples as part of the routine river sampling program, while the writer and his associates operated the laboratory, and, also conducted field inspections and collected special samples during the survey period.

TABLE 3-4

LOCATION OF SAMPLING STATIONS AND OTHER IMPORTANT POINTS

River Mile Point	Location
51.33	Beaudette Park Bridge in Pontiac
46.50	Small Bridge above Pontiac WTP (Station 1)
46.39	Pontiac WTP Effluent
45.74	Grand Trunk Railroad Bridge
45.05	Opdyke Road (U.S. 24)
44.87	M-59 Bridge (Station 2)
43.37	Auburn Heights Gage Bridge on M-59 (Station 3)
42.99	Squirrel Road Bridge (Station 4)
41.95	Hamlin Road Bridge (Station 5)
39.78	Adams Road Bridge (Station 6)
36.27	Livernois Road Bridge (Station 7)
34.98	Bridge west of M-150 (Station 8)
31.71	Yates Mill Bridge (Station 9)

For purposes of reference, sampling stations and other important points are listed in Table 3-4 above together with the associated river locations expressed in river miles above the mouth.

River Runoff and Channel Characteristics

Flow in the Clinton River below Pontiac is measured by a U.S.G.S. continuous recording stream gage located at Auburn Heights, Michigan in the critical stretch, 3.02 river miles below the Pontiac waste treatment plant outfall. Figure 3-4 shows the Auburn Heights continuous gage chart for the period August 17 to August 25, 1960, where it is seen that a definite hour to hour flow fluctuation exists produced primarily by flow variation from the Pontiac waste treatment plant. Average flow during the intensive sampling period August 23 to August 25, 1960, was 33 cfs at Auburn Heights while the average flow from the waste treatment plant was 16.9 cfs; thus, the treatment plant effluent made up more than 50 per cent of the total river flow during this period. Also, it is seen that while the average flow was 33 cfs, the actual flow ranged from 26 cfs to 46 cfs. While it was not possible to alter the flow pattern, it was possible to minimize this influence by collecting river samples every four hours around the clock for a 48-hour period through the critical section as previously discussed.

The Auburn Heights gage has been characterized by the U.S.G.S. as having an unstable stage-discharge relation which is particularly influenced during the summer period by varying amounts of aquatic growths. Because of this, it became necessary to develop an accurate stage-discharge curve from discharge measurements taken in July, August, and September, 1960, for purposes of converting gage height readings to discharge units.

Figure 3-5 is a daily hydrograph for the Auburn Heights gage for the spring and summer period of 1960 preceding the intensive survey period. It is apparent that steady flow conditions preceded the survey period for an extended time, with the exception of a few days in early August when the flow went up to 76 cfs on August 3, and then dropped rapidly again.

Channel characteristics were available as a result of cross section work conducted by the staff of the Michigan Water Resources

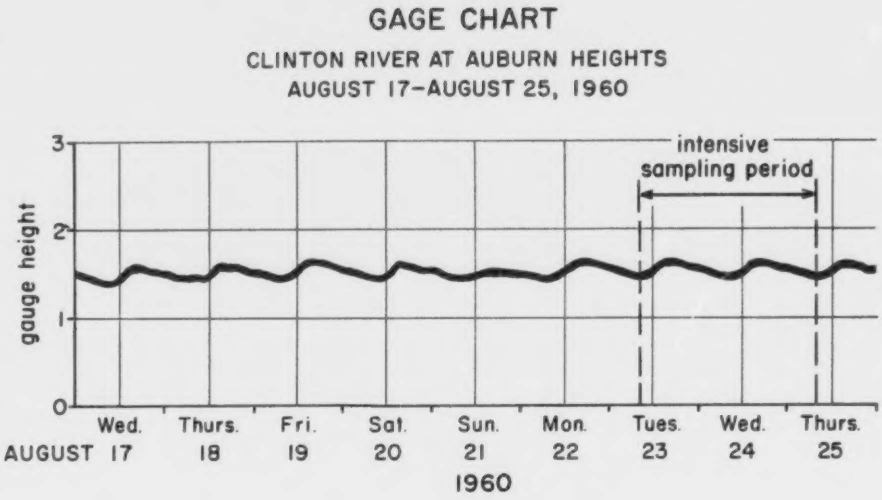

Figure 3-4

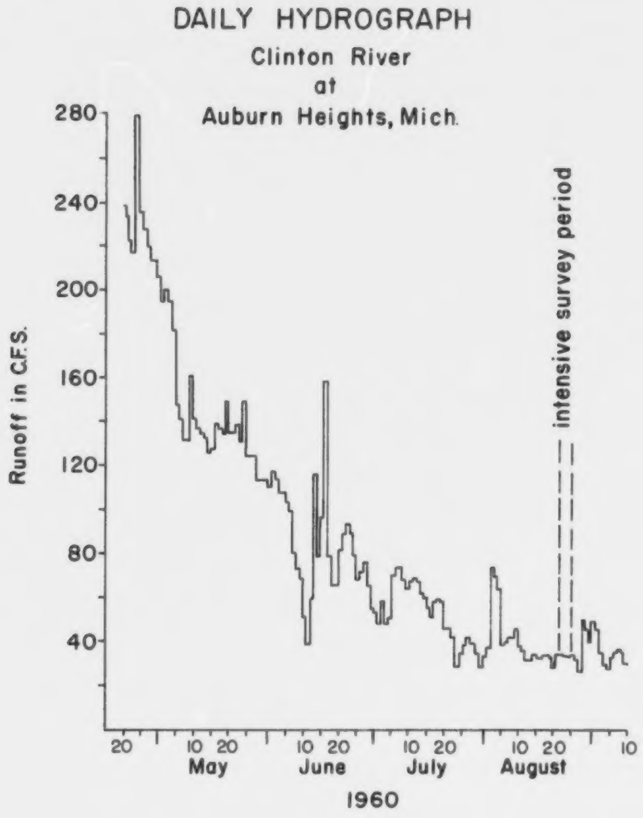

Figure 3-5

Commission during the period of June and July, 1958 at 500-foot intervals from Pontiac to Rochester. Because this information was made available by the Commission staff, it was not felt necessary to cross section the river again, and it only became necessary to adjust the volumes to the 1960 survey runoff of 33 cfs, using the appropriate Auburn Heights rating curve. These volumes, calculated on an end area basis, then became available for time of passage determinations on a displacement basis and, also, for reaeration evaluation. Mean depths through the critical section ranged from 1.12 feet to 2.04 feet, while widths ranged between 15 feet and 62 feet.

The Water Resources Commission staff report(2) presents the following description of the channel conditions in 1958:

> Immediately downstream from the Pontiac Sewage Treatment Plant the Clinton River channel consists of a series of pools formed by log jams and long canal-like runs averaging from 2.5 to 3.5 feet deep. Deposits of a light flocculent sludge ranging from 1 inch to 6 inches in depth were observed in the pools and more sluggish reaches between the sewage treatment plant and the M-59 bridge. From the M-59 bridge to just above Auburn Heights the river runs through a marsh. The channel is clear except for occasional weed beds and fallen trees. Just above M-59 in Auburn Heights the character of the channel changes to a fast falling one with numerous rocky riffles. Downstream from Squirrel Road at Auburn Heights the channel flattens out and there is considerable aquatic vegetation as far as Hamlin Road. The bottom consists of silt and sand. From Hamlin Road to Crooks Road the channel consists of a series of long pools about 2 feet deep, formed by small rock dams, interspersed with short reaches of rocky riffles and with considerable growth of aquatic vegetation. From Crooks Road to Rochester the channel is composed of stones and gravel. A large number of downed trees obstruct the flow somewhat; the flow is swift and numerous weed beds grow in this reach.

In 1960, the writer made a reconnaissance by boat of the Clinton River from the Pontiac waste treatment plant outfall to the M-59 bridge at Auburn Heights, and found the channel conditions to be essentially the same as described in 1958, with the exception of any noticeable sludge deposits in the section below the plant outfall.

River Dissolved Oxygen and BOD Relationships

One of the key elements of this research has been a critical evaluation of the relationships that existed during the intensive survey period of August, 1960 between the observed river dissolved oxygen conditions, and the observed river BOD conditions.

Inspection of the information early in the analysis period indicated that the dissolved oxygen concentrations were the most sensitive of the measurements, followed by routine river 5-day BOD determination in this order. As a result, greater reliance has been placed on the dissolved oxygen data than on the BOD information in the analysis that followed.

The observed dissolved oxygen concentrations in the Clinton River below Pontiac are presented in graphical form in Figure 3-6, with the concentrations expressed in per cent of saturation rather than mg/l. Inasmuch as the observed river water temperatures were essentially the same at all the sampling stations, there appeared to be no need to work in the units of mg/l.

Inspection of Figure 3-6 shows that a definite oxygen sag exists below Pontiac, with the low or critical concentration occurring in the vicinity of sampling stations 4 and 5 downstream from Auburn Heights. It is seen that the D.O. drops from a mean of about 82 per cent of saturation at Station 1 above the plant to a mean low of approximately 15 per cent of saturation in the vicinity of stations 3, 4, and 5, with one nighttime determination of 0 per cent at station 5. From here the dissolved oxygen concentration recovers, so that it reaches Rochester in a reasonably high state. An estimated observed mean oxygen profile has been indicated as a solid line in Figure 3-6, which will be referred to in subsequent discussion.

Although no absolute distinction exists between day and night samples, it is apparent that the daytime samples are as a group generally higher than the nighttime conditions, suggesting an influence of photosynthetic activity during the day. This is especially apparent at sampling stations 1, 7, and 8 where supersaturated conditions were noted during certain daytime sampling runs. Generally the weather was fair and warm with occasional periods of light cloud cover.

The first effort in the analysis of the data consisted of an attempt to independently check the observed dissolved oxygen

OBSERVED DISSOLVED OXYGEN
CLINTON RIVER
AUGUST 23-25,1960

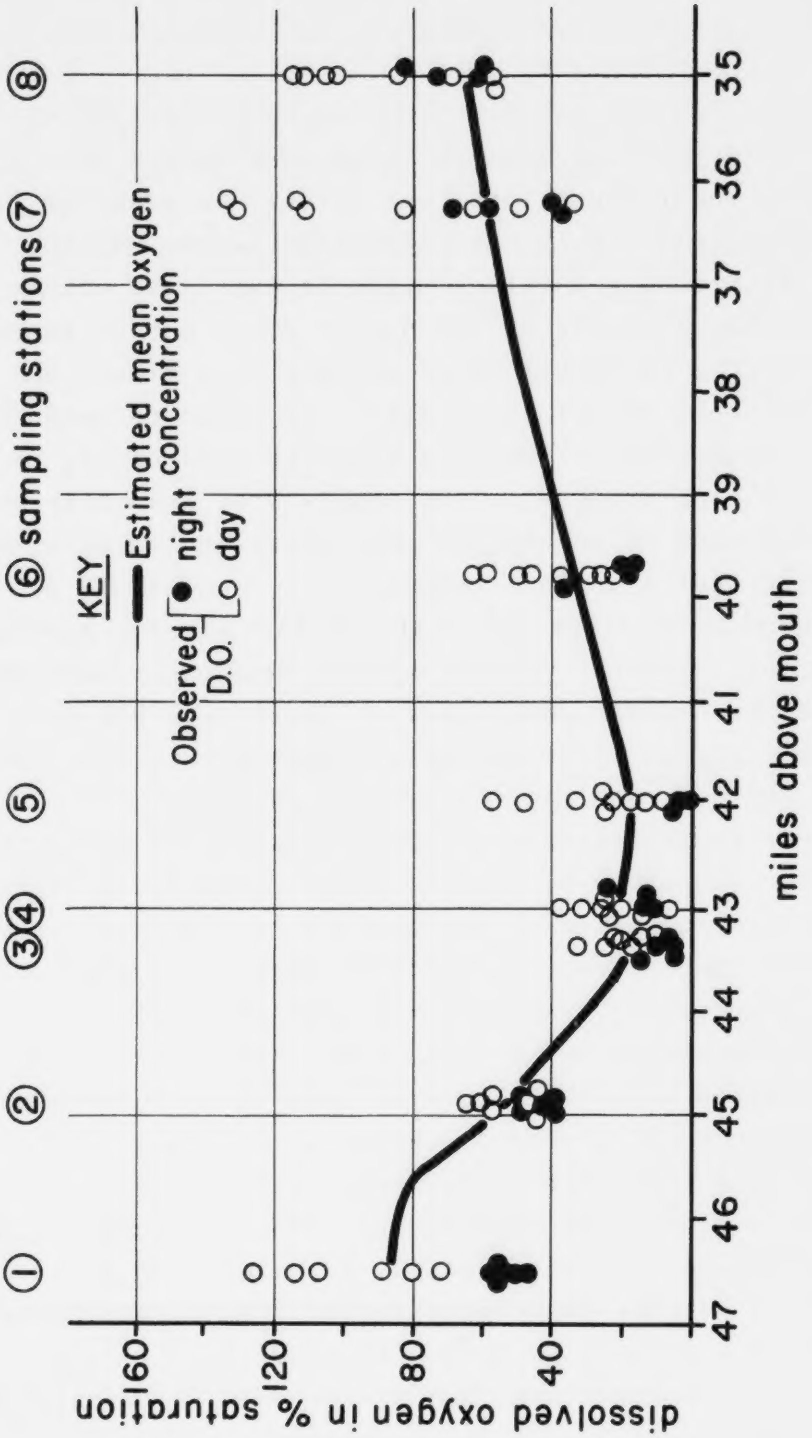

Figure 3-6

profile from a consideration of the BOD reductions at the river sampling stations, together with the oxygen assets of runoff and reaeration generally following the methodology suggested by Velz.(5) The advantages of this method of analysis over the conventional oxygen sag equation suggested by Streeter and Phelps(6) is that the observed dissolved oxygen data does not enter into the calculations, but rather, is reserved for independent comparison with the calculated oxygen results.

River BOD reductions might be expressed either in terms of population equivalents or lbs/day of BOD_5, but if expressed in the latter form, a conversion must be made to ultimate BOD before oxygen balances can be calculated. In order to make this conversion, knowledge of the deoxygenation constant k_1 is necessary.

Initial efforts in the analysis of the river BOD information consisted of working in population equivalents, on the assumption that a uniform laboratory k_1 applied to BOD samples collected from the river, and that a uniform river k_r applied throughout the critical stretch. Unfortunately, because of manpower shortages only one river water sample was collected for BOD rate analysis during the August, 1960 survey at sampling station 3 at Auburn Heights, with a resulting k_1 of less than .01.

After several exploratory calculations along the lines of a uniform laboratory k_1 and a uniform river k_r, a reasonable balance resulted using a laboratory $k_1 = 0.06$ and a river $k_r = 1.1$. One of the inconsistencies which developed was the fact that most of the laboratory k_1 values determined on samples of Clinton River water during the period of 1960-1962 were of the order of .01 or less. However, when k_1 values of less than .06 were used in the oxygen balance calculations, the resulting calculated ultimate BOD was more than the river could assimilate, causing calculated zero dissolved oxygen conditions for extended distances below Pontiac. Thus, it became apparent that any k_1 value less than .06 could not be used, but it was also demonstrated that a reasonable balance resulted if a k_1 as high as 0.1 was used.

The observed river BOD's expressed in population equivalents using a laboratory $k_1 = 0.06$ are plotted in Figure 3-7, with BOD on the log scale versus calculated time of passage on the linear

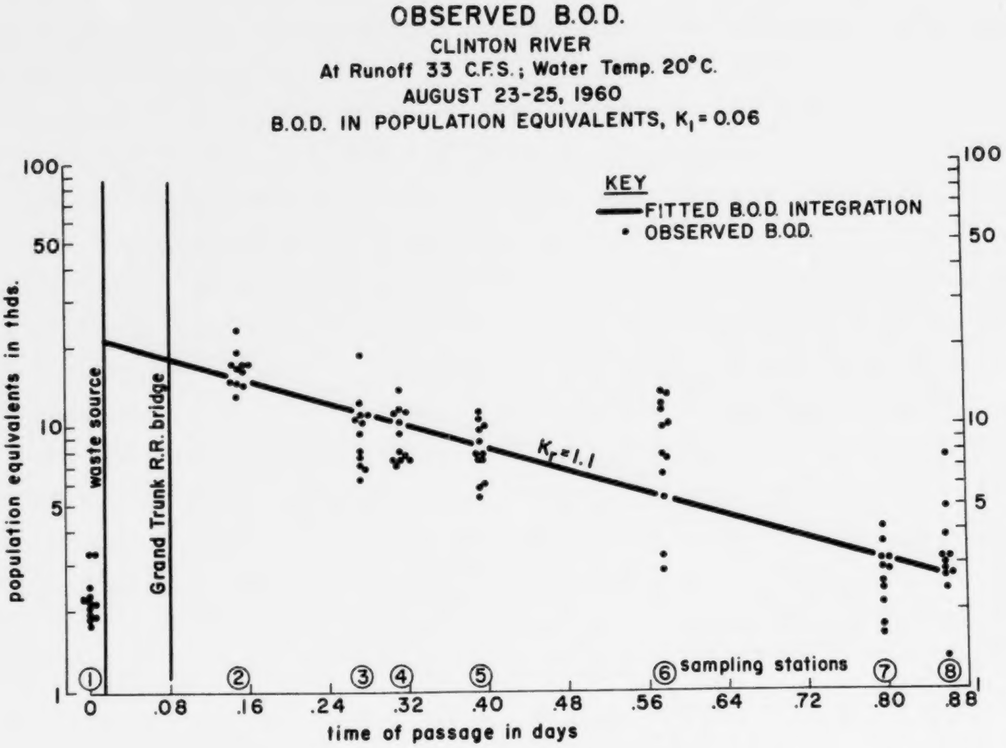

Figure 3-7

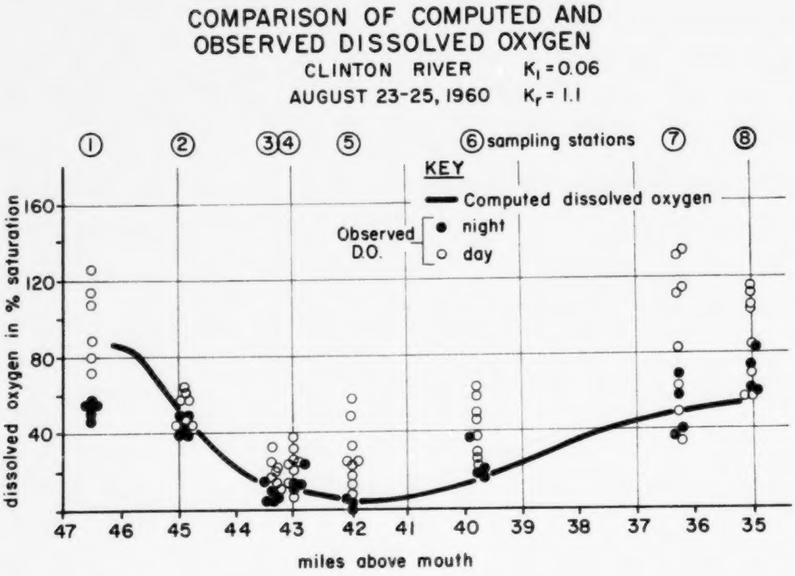

Figure 3-8

horizontal scale. It is apparent that considerable variation exists among the BOD results at any given sampling station, allowing the investigator considerable latitude in fitting a line through the data. The river $k_r = 1.1$ will hold regardless of the k_1 used, as the fitted line will merely be moved up or down on the population equivalent scale on a parallel basis.

Using the observed BOD as indicated by the fitted line with adjustments to be noted, the resulting dissolved oxygen profile was calculated using the methodology suggested by Velz.(5) Figure 3-8 shows a comparison of the computed and observed dissolved oxygen profiles during the August, 1960 survey period, indicating good agreement at the upper stations down to station 5, with the computed profile passing through the lower part of the observed data from stations 5 through 8. Further discussion of the factors entering into the Velz method of calculating oxygen balance in a river will be presented in the section of this report devoted to programming river dissolved oxygen calculations.

For purposes of comparison, Figures 3-9 and 3-10 are presented showing the balances resulting if a $k_1 = 0.1$ was used rather than the $k_1 = 0.06$ assumed in Figures 3-7 and 3-8. It is seen that in Figure 3-9, involving a plot of observed river BOD's expressed in population equivalents, the same river $k_r = 1.1$ holds. Looking at Figure 3-10 showing a comparison of the computed and observed dissolved oxygen values, it is seen that excellent agreement exists at all stations with the possible exception of the low point in the sag at stations 3, 4 and 5. Here the computed profile passes through the upper part of the data rather than through the mean. This further demonstrates, therefore, that a k_1 value in the range of 0.06 to 0.1, used together with a river $k_r = 1.1$ could be employed in calculating an oxygen balance that would be in reasonable agreement with the observed data.

As a result of initial efforts at oxygen balance calculations during the winter months of 1960-1961, it became apparent that further information on D.O. values in the river below the Pontiac waste treatment was needed. No special measurements were made on the plant effluent during the August, 1960 survey as it

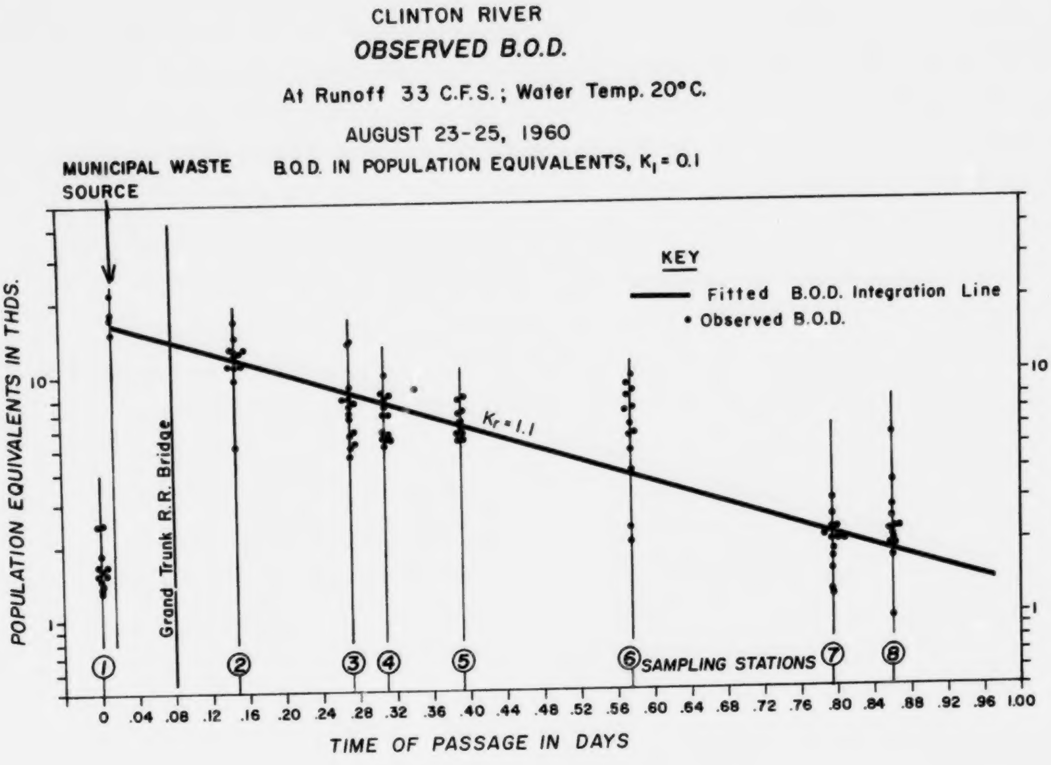

Figure 3-9

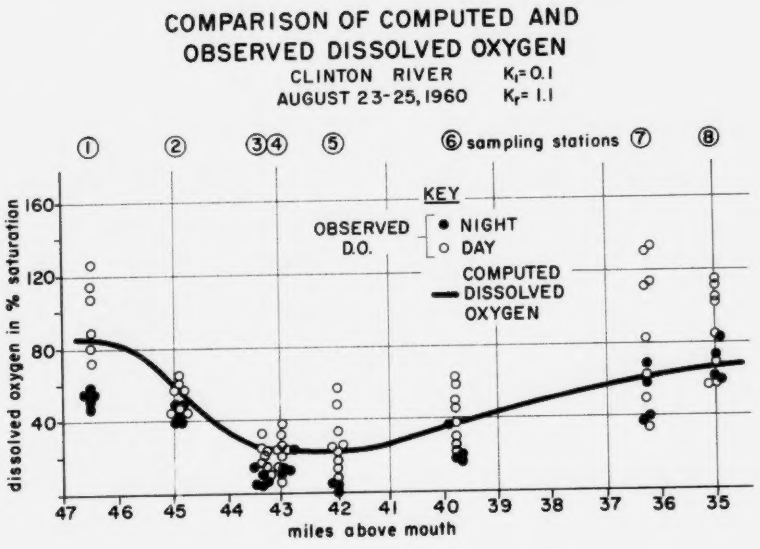

Figure 3-10

was assumed that the routine determinations made by the plant staff would be adequate. However, it became apparent that the low effluent D.O. values measured in the plant did not prevail in the river, and this assumed considerable importance because the plant effluent made up more than 50 per cent of the river flow during the August, 1960 survey. To collect this information, a special survey was conducted on July 12, 1961 in and around the Pontiac plant, which fortunately was under almost identical runoff and loading conditions as prevailed during August 23-25, 1960. Of special note was a mean river dissolved oxygen concentration of approximately 82 per cent of saturation determined from samples collected at a station about 50 yards downstream from the plant outfall by wading. This, then, served as a D.O. starting point below the outfall rather than a calculated figure previously used.

In addition to the oxygen conditions, the amount of chlorine residual was measured at various points in the plant and in the river. As will be shown herein later, a residual was measured in the river as far downstream as the Grand Trunk Railroad bridge at M.P. 45.74. The assumption has been made that because of this residual, no BOD has been exercised on the D.O. assets of the stream from the plant outfall to the railroad bridge. In other words, as a result of this influence, all theoretical calculations for oxygen balance start at the railroad bridge, rather than the plant outfall. If this assumption had not been made, the calculated oxygen profile would drop much faster than the observed values, completely missing the observed data at sampling station 2 at M-59 bridge. It is interesting that Schroepfer et al.(7) in a recent paper given at the 1st International Conference on Water Pollution Research in London has suggested that effluent chlorination might be used as a means of BOD reduction and retardation. While the primary purpose in chlorinating the effluent of the Pontiac waste treatment plant is for the public health objective of killing pathogenic organisms, it has the secondary effect of BOD reduction below the plant during the low flow periods. Snow(8) has indicated that the application of chlorine to sewage accomplishes a reduction of BOD which is generally considered to be real as well as apparent.

He further states that even if chlorine is applied for the disinfection of sewage effluents, it causes a reduction of BOD concurrent with the accomplishment of this purpose.

Another assumption made in the oxygen balance calculations is that any demand from sludge deposits or biological growths was a demand resulting from equilibrium accumulations. In other words, any BOD removed between stations as represented in Figures 3-7 and 3-9 constitutes a demand on the oxygen assets of stream rather than going into storage. This subject has been covered elsewhere by Velz,(9) and Velz and Gannon.(10) Inspection of the daily hydrograph for Auburn Heights gage for the spring and summer of 1960 preceding the August, 1960 survey as presented in Figure 3-5, bears out the assumption of equilibrium accumulation.

Recognizing that the assumption of a uniform laboratory k_1 value has not been fully borne out, a second type of analysis has been made starting with the observed mean dissolved oxygen profile, and working backwards from this and the river k_r data to determine the necessary laboratory k_1 rate.

Figure 3-11 shows the observed BOD in lbs/day of BOD_5, rather than population equivalents, plotted on a log scale versus calculated time of passage on the horizontal linear scale. Through this observed BOD data, a line has been fitted, corresponding to a river $k_r = 1.1$ which is seen to be the same k_r used in Figures 3-7 and 3-9.

Starting with the observed mean D.O. profile of Figure 3-6, it has been possible to work backward to find the necessary ultimate BOD in population equivalents to account for the observed D.O. conditions. Also, using the fitted BOD line of Figure 3-11, it has been possible to determine the mean observed BOD drop between sampling stations expressed in lbs/day of BOD_5. With this BOD_5 information, together with the necessary ultimate population equivalent demand developed from the observed mean D.O. condition, it has been possible to calculate the necessary laboratory k_1 for each section of the river. The results of this analysis are presented in Table 3-5 as follows, where the conversion figure of 0.24 lbs/day of ultimate BOD equal to one population equivalent has been used.

OBSERVED B.O.D.

CLINTON RIVER
At Runoff 33 C.F.S.; Water Temp. 20° C.
AUGUST 23-25, 1960
B.O.D. IN LBS./DAY OF 5 DAY B.O.D.

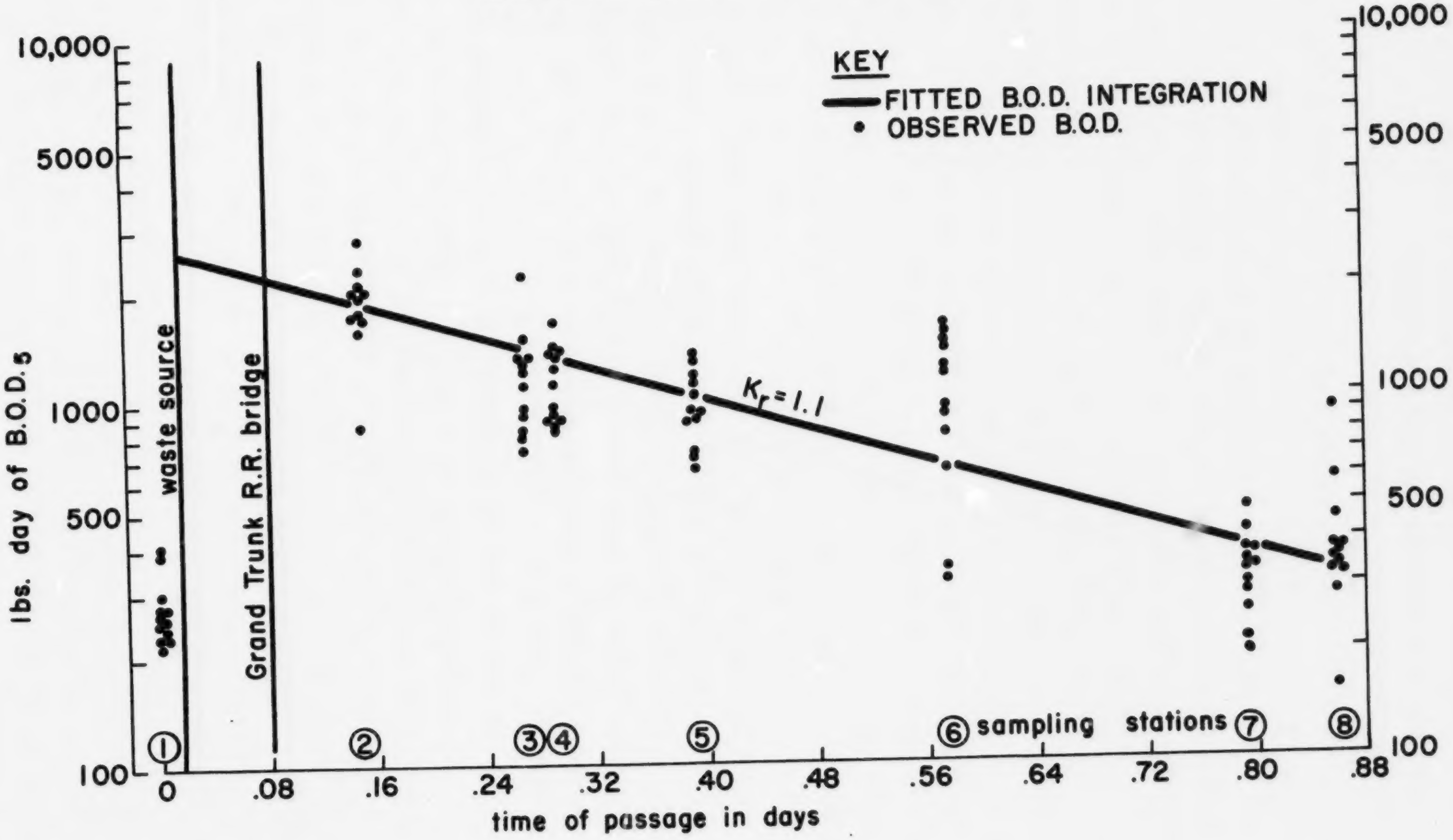

Figure 3-11

TABLE 3-5

CALCULATED LABORATORY k_1 TO CHECK OBSERVED RIVER CONDITIONS

M.P.	Station	Necessary P.E. to Check D.O. of Fig.3-6	Observed lbs/day BOD_5 from Fig.3-11	Lbs/day BOD_5 drop Between Station	Calculated k_1 for Section
45.74	Railroad Bridge		2,200		.082
		2,381		350	
44.87	M-59 (Sta. 2)		1,850		
		3,835		460	.060
43.37	Auburn Heights (Sta. 3)		1,390		
		196		70	---
42.99	Squirrel Road (Sta. 4)		1,320		
		1,875		290	.090
41.95	Hamlin Road (Sta. 5)		1,030		
		2,380		380	.095
39.78	Adams Road (Sta. 6)		650		
		1,685		280	.103
36.27	Livernois Road (Sta. 7)		370		
		335		60	.119
34.98	Bridge West of M-150 (Sta. 8)		310		

Taking the calculated k_1 values of the last column of Table 3-5 and weighting them in accordance with distance, gives an overall weighted k_1 for the section of the river from M.P. 45.74 to M.P. 34.98 of 0.094. On the other hand, if a weighted k_1 is calculated for the section from the railroad bridge to station 3 at Auburn Heights, corresponding to the section where the river D.O. is dropping rapidly, it is found to be 0.068. This type of analysis, therefore, appears to support the previous analysis where it was concluded that a k_1 in the range of .06 to .1 gave the best agreement between the calculated and observed river D.O. data. However, it is again apparent that the lower range of the k_1 of 0.06 is still substantially above the usual laboratory k_1 values of .01 or less.

It is important to appreciate the significance of the k_1 rate in converting observed BOD information, available in lbs/day BOD_5, to an ultimate expression of first stage demand, either in terms of lbs/day BOD, ultimate, or to population equivalents. For example, for a load of 2700 lbs/day BOD_5, it is seen that with a $k_1 = 0.1$, the ultimate load would be 16,450 population equivalents, with a $k_1 = 0.06$, the ultimate load would be 22,600, while with a $k_1 = 0.01$ the ultimate load would be 103,500 population equivalents. Thus, the importance of the k_1 is apparent where it is seen that a difference between 0.06 and 0.01 could exert a substantial influence on the ultimate river BOD.

It is evident from what has been presented that the river $k_r = 1.1$ is approximately ten times the calculated k_1 rate range of 0.06 to 0.1 obtained by working backward from river D.O. and BOD data, and this figure in turn is approximately ten times the k_1 rate of 0.01 or less obtained from laboratory studies on river water samples using the jug reaeration technique. The question might be raised--why is this? Is there an adequate explanation to account for this difference such as sludge deposits(9) or possibly biological extraction and accumulation as reported occurring in several rivers by Velz and Gannon?(10)

Examination of the river channel from the Pontiac outfall to Auburn Heights showed no extensive sludge deposits that could account for the high river k_r. While deposition might occur if settleable solids were present in some of the small pool areas resulting from log jams as reported by the Michigan Water Resources Commission in 1958, they were not of an extensive nature; this, therefore, suggests sludge deposition as exerting a minimal influence on the river k_r.

During low flow periods, extensive contact opportunity exists between the river water and (1) the channel bottom and sides, (2) numerous obstructions caused by fallen trees and limbs, and (3) abundant aquatic growths that completely fill the channel in some sections of the river between Pontiac and Rochester. Microscopic examination of specimens collected from these various obstructions and aquatic growths indicated the presence of a slime film, which is presumed to function much as the slime growth in a trickling filter in extracting and storing organic materials. In addition to these examinations, several plankton and bottom samples were collected during the summer of 1961 revealing a general array of microorganisms usually found in polluted waters, but indicating no predominant organisms such as Sphaerotilus natans which has been found in other rivers exhibiting gross biological extraction, such as the Paw Paw River in Michigan. To supplement these findings, a series of tiles were mounted on a special rack constructed in the river at sampling station 3 at Auburn Heights, during the summer of 1961, with tiles removed regularly during the summer for evaluation. Here, again, microscopic examination revealed the presence of a slime growth with no predominant organism. From this evidence it can be concluded that some type of biological extraction and accumulation was taking place, much as would occur in a trickling filter, with no specific organism predominating.

The question might be raised--Is this the only factor responsible for the high river $k_r = 1.1$? To further test the major hypothesis of the study, certain of the BOD rates of Clinton River water were conducted under continuous mixing in sealed BOD bottles using magnetic stirrers. It was found, as will be shown herein later, that the BOD rate conducted under continuous mixing was definitely higher than a similar rate run in parallel on the same original sample but under quiescent conditions. For example, BOD rates run on a sample of Clinton River water collected at sampling station 3 at Auburn Heights on July 27, 1961 had a $k_1 = 0.11$ on the mixed sample in contrast to a $k_1 = 0.01$ on the non-mixed sample, indicating a ten-fold difference. Thus, it can be concluded that mixing does have an influence on the k rate, suggesting that the high river $k_r = 1.1$ might be due to a combination of biological extraction and accumulation, and certain other natural conditions such as turbulence which have accelerated the BOD reaction. It will be shown later in connection with the Tittabawassee River case study, that a more clear-cut condition exists where biological extraction is ruled out, and the difference between the k_1 and k_r is attributed to an increased oxidation rate in the river.

Lordi and Heukelekian(11) have independently supported the findings of this investigation showing that mixing does cause an increase in the deoxygenation constant k_1.

Next the question might be asked--Is there any explanation for the differences between the $k_1 = 0.01$ or less, usually found in the laboratory studies, and the $k_1 = 0.06$ to 0.1 calculated by working backwards from the observed river D.O.'s and BOD's? Careful examination of typical quiescent laboratory rate studies conducted on Clinton River water showed that generally an S-type curve resulted, i.e., there was a period of slow oxygen utilization, followed by period of rapid utilization, and then finally a period of leveling off. When nitrogen studies were conducted in conjunction with the regular rate determinations, it was shown that the period of rapid oxygen utilization was associated with active nitrification, i.e., in addition to the normal carbonaceous demand, the nitrogen component was also utilizing oxygen going from NH_3 to NO_2 to NO_3. Critical evaluation of BOD rate studies of samples collected at sampling station 3 at Auburn Heights and sampling station 6 at Adams Road, where nitrogen determinations were made at the beginning, mid-point, and end of the rate study, showed that in almost all cases active nitrification had started before 5 days with the Adams Road samples, while in about 50 per cent of the cases it had started within the first 5 days in the Auburn Heights samples. Thus, it appears that nitrification has been an influence in the BOD rate studies conducted on Clinton River water, and no doubt has influenced the value of k_1 where only the first 5 days were used in rate study analysis.

While nitrification has appeared to influence the laboratory BOD rates, no evidence is available to indicate it has influenced the river k_r, at least, not to the low point in the oxygen sag at stations 3 and 4 at Auburn Heights. Nitrogen determinations run on river water samples show no active nitrification between the Pontiac treatment plant outfall and station 3 at Auburn Heights. As a result of these findings, investigations are underway to study the influence of nitrification on the BOD test, and also, the effect on the river oxygen balance. Courchaine(12) of the Michigan Water Resources Commission has reported on a condition of active nitrification in the Grand River below Lansing, Michigan.

In the analysis procedure followed, heavy reliance has been placed on the accuracy of the reaeration calculations following the procedures of Velz.(5) It is the feeling of the writer that the Velz method is a sound one having been successfully applied to many practical river situations since it was proposed in 1939. Certain of the empirical components, especially the time of mix relationships, have been adequately defined for the ranges ordinarily found in river situations. In recent years, O'Connor and Dobbins(13) and also, Churchill(14) have proposed similar methods of reaeration calculation employing mean river depth and velocity.

All river time of passage data has been determined on a calculated basis, using the displacement method, from a knowledge of the river volumes and associated runoffs. An effort was made during the summer of 1962 to check the calculated times by means of a Rhodamine B dye together with a sensitive fluorometer. Unfortunately, the limited availability of the fluorometer equipment prevented the collection of any meaningful information.

As a result of the information collected on the Clinton River including the intensive survey of August, 1960, together with the 1961 field and laboratory studies, no firm acceptance or rejection of the major hypothesis of the study can be made, i.e., where k_r is higher than expected from a knowledge of the waste oxidation rate and time of passage, the cause is not due to an increased oxidation rate in the river, but rather due to some abnormality such as sludge deposition or biological extraction and accumulation. It appears logical to assume from the evidence available that the river $k_r = 1.1$ is due to a combination of both accelerated oxidation rate and biological extraction and accumulation. Also, it can be assumed that the low laboratory rates have been due among other things to the influence of nitrification toward the end of the standard 5-day incubation period, thereby causing low k_1 values where the conventional monomolecular computational procedures of analysis are employed.

July, 1961 Water Quality Survey

For purposes of collecting oxygen information around and below the Pontiac waste treatment plant, together with chlorine residual information, a special survey was conducted on July 12, 1961. Fortunately, the runoff and other conditions were the same as those prevailing during the August 23-25, 1960 survey resulting in the acquisition of excellent supplementary information. All laboratory analyses were completed in accordance with the procedures recommended in Standard Methods(4) shortly after collection at a temporary laboratory established on the grounds of the Pontiac waste treatment plant. The oxygen increase resulting from the drop over the effluent weir of the chlorine contact tank is presented in another section of this report, while all the detailed data from the survey is presented in Appendix I-C. As part of the construction activity associated with the Pontiac waste treatment plant addition, the Clinton River channel was altered from the Grand Trunk Railroad bridge to Opdyke road starting in August, 1961. Fortunately all of the critical river water sampling activity had been completed by this time.

Chlorine Residual Survey

One of the important findings of the July 12, 1961 effort was the fact that a chlorine residual persisted in the Clinton River as far downstream as the Grand Trunk Railroad bridge. Figure 3-12 shows a plot of chlorine residual, where a residual of about 0.18 mg/l was observed at the railroad bridge, while no residual was measured at the M-59 bridge or regular sampling station 2. The importance of this finding in supporting the assumption of BOD retardation down to the railroad bridge has been discussed previously under river D.O. and BOD relationships pertaining to the August, 1960 survey. Baity et al.(15) some 30 years ago, reported on the improvement of water quality of Bolin Creek below Chapel Hill, North Carolina as a result of chlorination of the effluent from the waste treatment plant during the summer low flow period.

CHLORINE RESIDUAL SURVEY

CLINTON RIVER
JULY 12, 1961

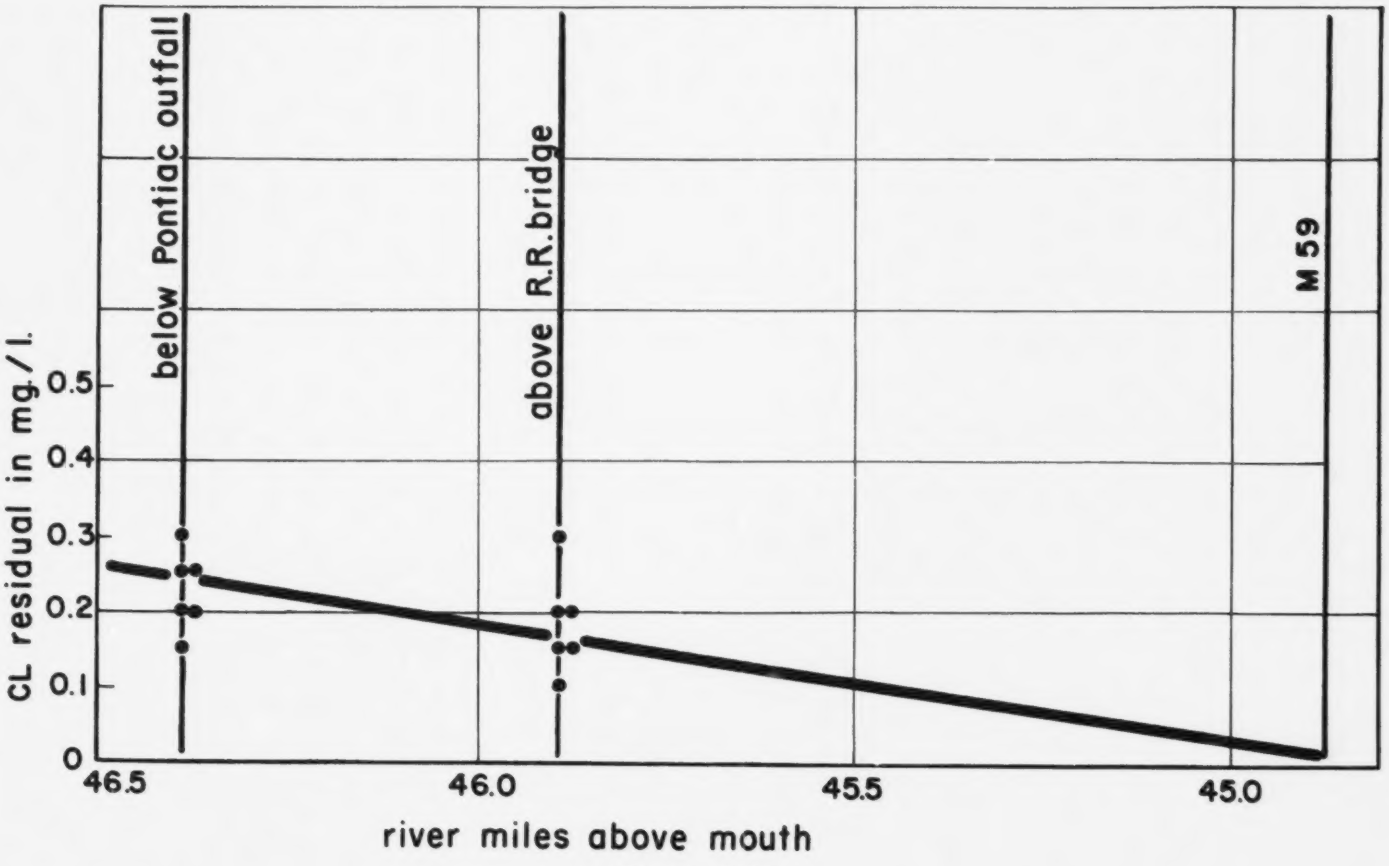

Figure 3-12

Summary and Conclusions

This section of the report has been concerned with the presentation of data and a discussion of results relating to river surveys conducted in 1960 and 1961 on the Clinton River between Pontiac and Rochester, Michigan. As a matter of background, material is presented on the Clinton River Basin including the results of drought flow analysis at the Mount Clemens and Auburn Heights gages. Major focus has been on the August, 1960 intensive water quality survey including pollution sources and magnitudes, the river sampling program, the river runoff and channel characteristics, and river dissolved oxygen and BOD relationships.

BOD removal rates in the river were high with a k_r of approximately 1.1, while the k_1 rate calculated by working backward from river D.O. and BOD data was in the range of 0.06 to 0.1, and the k_1 rate obtained from laboratory studies on river water samples was in the range of 0.01 or less. Extensive contact opportunity exists between the river water and (1) the channel bottom and sides, (2) numerous obstructions caused by fallen trees and limbs, and (3) abundant aquatic growths that completely fill the channel in some sections. Microscopic examination of specimens collected from these obstructions indicated the presence of a slime film suggesting, therefore, the strong possibility of biological extraction and accumulation. On the other hand, it has been demonstrated in the laboratory that BOD rates conducted under continuous mixing are higher than those conducted under the usual quiescent conditions. Thus, the conclusion is drawn that mixing does have an influence on the k rate, suggesting that the higher river $k_r = 1.1$ might be due to a combination of biological extraction and accumulation, and certain other natural conditions such as turbulence which have accelerated the BOD reaction. In addition, the assumption is made that low laboratory k_1 rates of 0.01 or less, have been due among other things to the influence of nitrification on the BOD test toward the end of the standard 5-day incubation period, thereby causing low k_1 values where the conventional monomolecular computational methods of analysis are employed.

As a result of the information collected on the Clinton River, no firm acceptance or rejection of the major hypothesis of the study can be made, i.e., where k_r is higher than expected from a knowledge of the waste oxidation rate and time of passage, the cause is not due to an increased oxidation rate in the river, but rather due to some abnormality such as sludge deposition or biological extraction and accumulation. To the degree that an increased oxidation rate is present in the river, the hypothesis is rejected, but, inasmuch as there is a strong suggestion of biological extraction and accumulation, and it has not been possible to assess the relative influence of each factor, no firm conclusion can be drawn.

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SECTION IV

TITTABAWASSEE RIVER

As a second case study, the Tittabawassee River between Midland and Saginaw was selected for intensive investigation. Several factors entered into the selection of this river, including previous water quality data indicating a river k_r higher than normal, a uniform river channel with no tributaries entering the selected section, all of the waste entering the river at the beginning of the critical section or brought from upstream sources, the major waste source from an industry rather than a municipality, and finally the agreement of the Dow Chemical Company to cooperate in the study by supplying information and helping in certain phases of the field effort.

This section of the report presents background information on the Tittabawassee River, including the results of analysis of the river drought flows at Midland. In addition, an extensive discussion is presented of the August, 1961 intensive river water quality survey covering the pollution sources and magnitudes, the sampling program, the river runoff and channel characteristics, the river temperature conditions, and the river dissolved oxygen and BOD relationships.

Basin Description

The Tittabawassee River Basin (Figure 4-1), located in the central part of the lower peninsula of Michigan, is a tributary of the Saginaw River which discharges into Saginaw Bay (an arm of Lake Huron) at Bay City, Michigan. Generally it is fan shaped in appearance, with the main tributaries consisting of the Pine River, the Chippewa River, and the Upper Tittabawassee River converging at Midland, Michigan to form the section of the river under study.

The total drainage area at the mouth of the river has been estimated as 2,515 square miles,(1) while the U.S.G.S. reports the

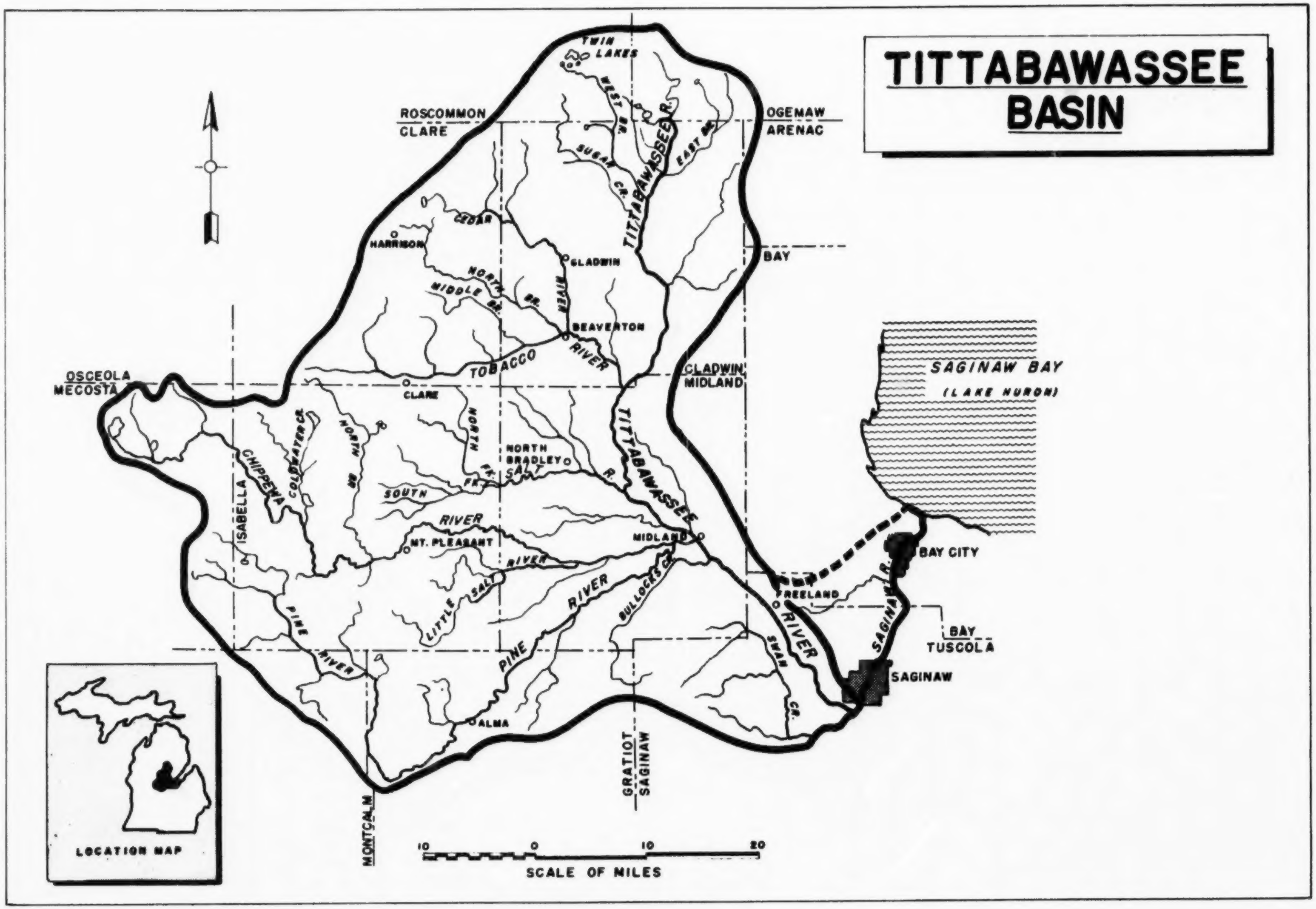

TITTABAWASSEE BASIN
TWIN LAKES
WEST BR.
EAST BR.
SUGAR CR.
TITTABAWASSEE R.
ROSCOMMON
CLARE
OGEMAW
ARENAC
BAY
CEDAR
HARRISON
GLADWIN
NORTH BR.
MIDDLE BR.
RIVER
BEAVERTON
TOBACCO RIVER
CLADWIN
MIDLAND
OSCEOLA
MECOSTA
CLARE
SAGINAW BAY
(LAKE HURON)
CHIPPEWA
COLDWATER CR.
NORTH BR.
NORTH FK.
NORTH BRADLEY
SALT
SOUTH FK.
RIVER
TITTABAWASSEE R.
ISABELLA
MT. PLEASANT
MIDLAND
RIVER
LITTLE SALT
BULLOCKS CR.
PINE RIVER
PINE RIVER
ALMA
FREELAND
RIVER
SAGINAW R.
BAY CITY
BAY
TUSCOLA
SWAN CR.
SAGINAW
GRATIOT
SAGINAW
MONTCALM
LOCATION MAP
10 0 10 20
SCALE OF MILES

Figure 4-1

tributary drainage area at the Midland gage on the main river as 2,400 square miles. Thus, it is apparent that most of the drainage area is above Midland, indicating negligible runoff contribution downstream, making this an ideal study situation from the hydrology standpoint. In addition, Sanford Reservoir located upstream from Midland on the main Tittabawassee River, has proven useful in creating artificial drought conditions in the lower river by holding back normal runoff for short periods of time of one or two days in order to conduct water quality surveys and time of passage studies.

The Tittabawassee River Basin is bounded on the south by the Grand, Flint, Shiawassee, and Cass Basins, on the east by land adjacent to Saginaw Bay, on the northeast by the Rifle Basin, on the north by the Au Sable Basin, and on the west by the Muskegon Basin.

Most of the population in the study area is centered in and around Midland with the 1960 population for the City of Midland reported as 27,779, while the Midland County population for 1960 is reported as 51,450. Major employment is at the Dow Chemical Company located in Midland.

Others have presented more detailed reports on various phases of the water resources in the Tittabawassee River Basin including the work of Velz,(2) the Michigan Water Resources Commission(3) and most recently that of Wagoner.(4)

Drought Flows at Midland

As a frame of reference for discussion of water quality data collected under low flow conditions, drought flows as analyzed and reported by Velz and Gannon(1) for the Midland gage on the Tittabawassee River, adjusted for diversion, are summarized as follows in Table 4-1.

TABLE 4-1

DROUGHT FLOWS IN CFS

Tittabawassee River at Midland
(adjusted for diversion)

Frequency of Occurrence	1 Day	7 Days	15 Days	30 Days
Most Probable	274	341	375	414
1 in 5 Years	219	271	308	338
1 in 10 Years	197	242	278	307
1 in 20 Years	177	217	253	278

August, 1961 Water Quality Survey

To test the major hypothesis of this study, a special water quality survey was conducted through the critical section of the river under steady flow and pollution loading conditions during the period August 23-25, 1961. By special arrangement with the Dow Chemical Company, the river flow and waste loads were maintained at a constant level throughout a 48-hour around the clock intensive sampling period. Previous water quality data collected by the Dow Chemical Company and made available to the writer, together with water quality data collected by the Michigan Water Resources Commission and previously analyzed by Velz(2) proved invaluable in the design of this survey.

Pollution Sources and Magnitudes

All of the major pollution sources influencing water quality in the critical section of the Tittabawassee extending from Midland to Saginaw, either originate in or near Midland or are brought to this section from upstream sources. Here, again, is another favorable factor making this a good study situation in that a determination of pollution load at the beginning of the section adequately defines the pollution load tributary to the lower river.

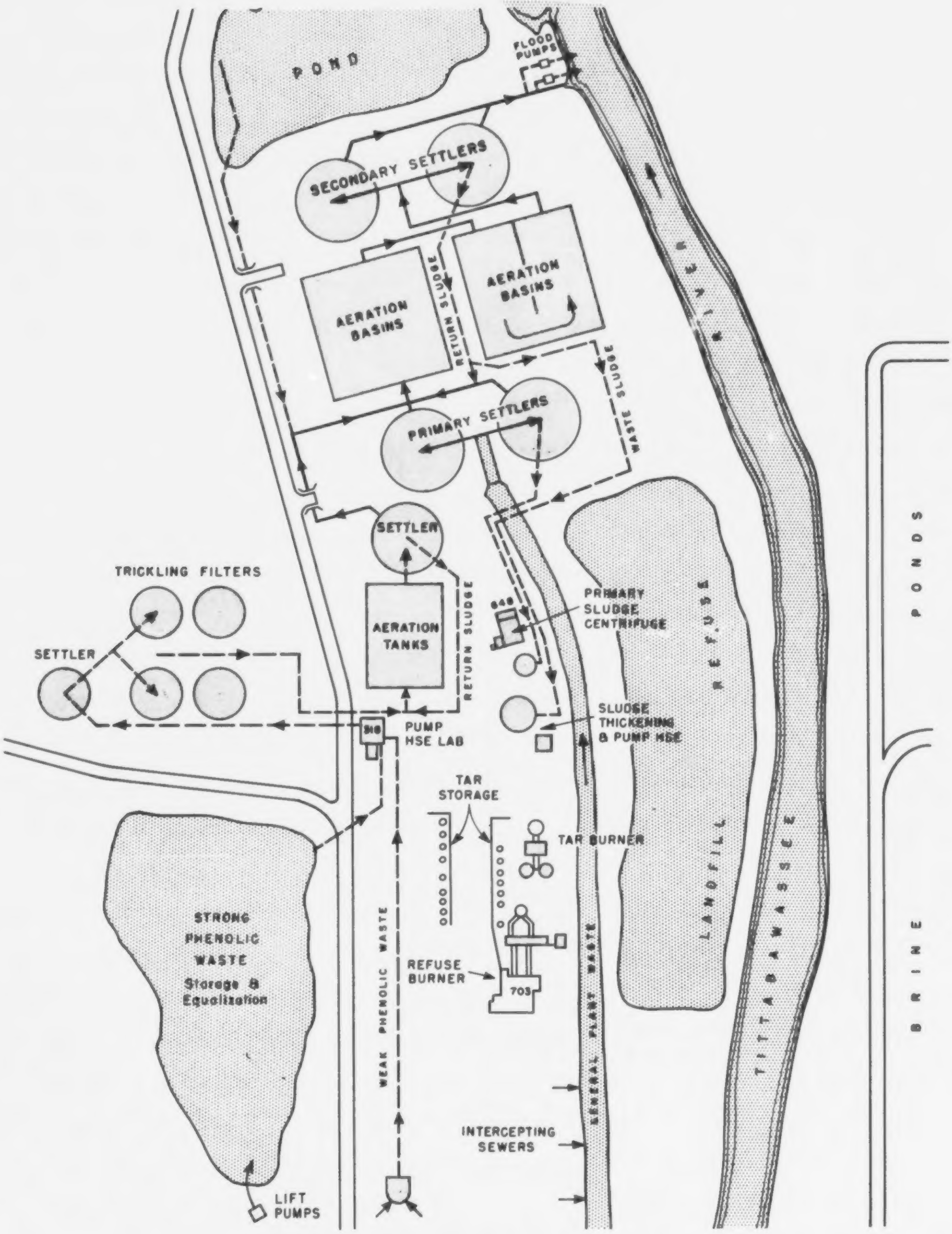
While major focus in this study has been around behavior of organic material in the river, it was felt necessary to evaluate the magnitude of the BOD contribution of all the known major sources of pollution by sampling the source at a point prior to discharge to the river. In most cases, this constituted a single grab sample collected by the writer and his associates at some time during the survey period.

In addition, routine data of plant effluent BOD_5 quality was supplied by the staff of the Dow Chemical Co. waste treatment plant which was found to be in excellent agreement with an independent analysis conducted in the laboratories of the School of Public Health. As an illustration, the BOD_5 as determined by Dow amounted to 3.6 mg/l, while that determined by the School of Public Health amounted to 3.6 mg/l using the jug aeration technique. Figure 4-2 is a flow diagram of the waste treatment facilities of the Dow Chemical Company at Midland, showing the complexity of the operations for treating the various plant liquid wastes.

Loadings to the river contributed by the City of Midland waste treatment plant are those reported by the plant operating staff. Unfortunately, an 8-hour composite sample of the plant effluent made available to the writer had a higher BOD than anticipated, resulting in the selection of inadequate dilution in the laboratory procedure. Because of this, only the results supplied by the plant staff are reported in this study.

In addition to samples collected at the various waste sources, five river sampling stations were routinely occupied in and above Midland. These stations are numbered as 1 through 5 in Figure 4-3, and included the Currie Parkway bridge on the main Tittabawassee above Midland (Station 1), the Homer Road bridge above Midland on the Chippewa River (Station 2), the Frost Road bridge on the Pine River above Midland (Station 3), together with two stations on the Benson St. bridge over the Tittabawassee River in Midland (Stations 4 and 5).

Two important samples were collected by the writer and his associates by boat in the Tittabawassee River immediately below the discharge point of the Dow waste treatment plant on August 24. The first was collected in the effluent stream from the plant


POND
FLOOD PUMPS
SECONDARY SETTLERS
AERATION BASINS
AERATION BASINS
RETURN SLUDGE
WASTE SLUDGE
PRIMARY SETTLERS
SETTLER
TRICKLING FILTERS
SETTLER
AERATION TANKS
RETURN SLUDGE
646
PRIMARY SLUDGE CENTRIFUGE
518
PUMP HSE LAB
SLUDGE THICKENING & PUMP HSE
TAR STORAGE
TAR BURNER
REFUSE BURNER
703
STRONG PHENOLIC WASTE Storage & Equalization
WEAK PHENOLIC WASTE
GENERAL PLANT WASTE
INTERCEPTING SEWERS
LIFT PUMPS
REFUSE LANDFILL
TITTABAWASSEE RIVER
BRINE PONDS

DOW CHEMICAL CO.
WASTE TREATMENT FACILITIES
MIDLAND, MICHIGAN

Figure 4-2

which could be easily identified by the mild foam present, while the second was collected across the river in what was clearly the upstream flow and did not include the plant effluent. Thus, information became available as to the total river load below the plant, together with the relative contribution coming from the plant, as distinct from that coming to the plant from upstream sources. This, then, served as an excellent starting point for any theoretical calculations of water quality conditions in the Tittabawassee River below Dow. Looking at these figures as tabulated in Table 4-2, it is seen that the Dow contribution is 2,726 lbs/day BOD_5, while the upstream load is 7,578 lbs/day BOD_5, indicating that during the August, 1961 survey period more of the total river BOD load was contributed from upstream sources than from the Dow waste treatment plant. Moreover, the dissolved oxygen concentrations determined at these two river stations served as excellent starting points for theoretical oxygen balance calculations in the lower river.

It is interesting to note that the BOD_5 of the Dow waste treatment plant effluent as measured by the jug reaeration technique on an undiluted sample amounted to 3.6 mg/l, while the effluent sample collected in the river just below the discharge point had a BOD_5 of 6.8 mg/l using a 50% dilution, or a BOD_5 of 4.75 mg/l using a 100% dilution. It is apparent, therefore, that the dilution used in the BOD_5 procedure does have a distinct influence on the resulting concentration particularly in the dilution ranges of 100%, 50%, 25%, etc. commonly used in river BOD determinations. This subject will be explored further in a subsequent section of this report. Where relatively large flow volumes are dealt with such as in the case of the Dow waste treatment plant effluent involving 48 MGD, it is seen a BOD_5 of 3.6 mg/l means a river load of 1,441 lbs/day BOD_5, while a BOD_5 of 6.8 mg/l means a river load of 2,726 lbs/day BOD_5.

Table 4-2 is a summary of the organic BOD load conditions in and around Midland during the August, 1961 survey, including both onshore and river BOD measurements, together with the associated runoff information reported either by U.S.G.S., the Dow Chemical Co. staff, or the City of Midland waste treatment plant staff.

TABLE 4-2

BOD MEASUREMENTS ON WASTE SOURCES AND SELECTED RIVER LOCATIONS IN VICINITY OF MIDLAND DURING SURVEY PERIOD

Location	BOD_5	Flow	BOD_5 lbs/day
Tittabawassee River at Currie Parkway (Sta. 1)	2.27 mg/l*	73.2 cfs	896
Chippewa River at Homer Road (Sta. 2)	0.98 mg/l*	155 cfs	819
Pine River at Frost Road (Sta. 3)	12.9 mg/l*	95.5 cfs	6,641
Midland Waste Treatment Plant			
Effluent**	138 mg/l	2.29 MGD	2,636
By Pass**	234 mg/l	1 MGD	1,952
Tittabawassee River at Benson Street			
near Midland (Sta. 4)	7.65 mg/l*	74.7 cfs	3,081
opposite Midland (Sta. 5)	4.8 mg/l*	250 cfs	6,469
Dow Chemical Co.			
60-inch Drain	12.8 mg/l	34.1 MGD	3,640
Bullock Creek	3.8 mg/l	11 cfs	225
Waste Treatment Plant (effluent)	3.6 mg/l	48 MGD	1,441
Lingle Drain above 84" drain	4.5 mg/l	9.5 MGD	357
84" drain	5.4 mg/l	3.6 MGD	162
Tittabawassee River Below Treatment Plant Outfall in Effluent Stream	6.8 mg/l (50% dilution)	74.36 cfs	2,726
Tittabawassee River Opposite Dow Treatment Outfall in Flow from Upstream	5.6 mg/l (50% dilution)	251 cfs	7,578

*Mean

**Reported by Plant Operator

River Sampling Program

In order to collect the necessary water quality data, a river sampling program was designed to routinely collect samples from 11 river sampling stations every 4 hours, day and night, over a 48-hour period, making a total of 132 routine samples. The stations are indicated by number on Figure 4-3, with an additional station indicated as station 10, which was sampled only during the daylight hours because it involved wading into the river at a relatively inaccessible location.

Routine analysis of each sample consisted of temperature, pH, D.O., and BOD_5, which in most cases was determined in two dilutions. The results of this survey for each station are presented in detail in Appendix II-A of this report. Each sampling run took approximately four hours, with sample collection starting at station 1 above Midland and ending at station 12 on the outskirts of Saginaw. From here the samples were taken immediately to a temporary laboratory established at the Saginaw water treatment plant where all the analyses were completed as soon as possible in accordance with the procedures recommended in the 11th Edition of Standard Methods.(5) Dissolved oxygen samples were fixed in the field at the time of collection, with the final titrations completed in the laboratory at the end of each run. BOD samples were incubated in a basement room of the Saginaw water treatment plant, where the temperature remained constant at 20°C. during the survey period, and were then transported back to the School of Public Health laboratories and incubated at 20°C. for the remainder of the 5-day period before completion of the test. Sampling personnel for the routine river sampling program were supplied by the Dow Chemical Company, while the writer and his associates operated the laboratory, and, also, conducted field inspections and collected special samples during the survey period.

For purposes of reference, lower river sampling stations and other important points are listed in Table 4-3, together with the associated river locations expressed in river miles above the mouth.

TITTABAWASSEE RIVER

Midland to Saginaw
Michigan

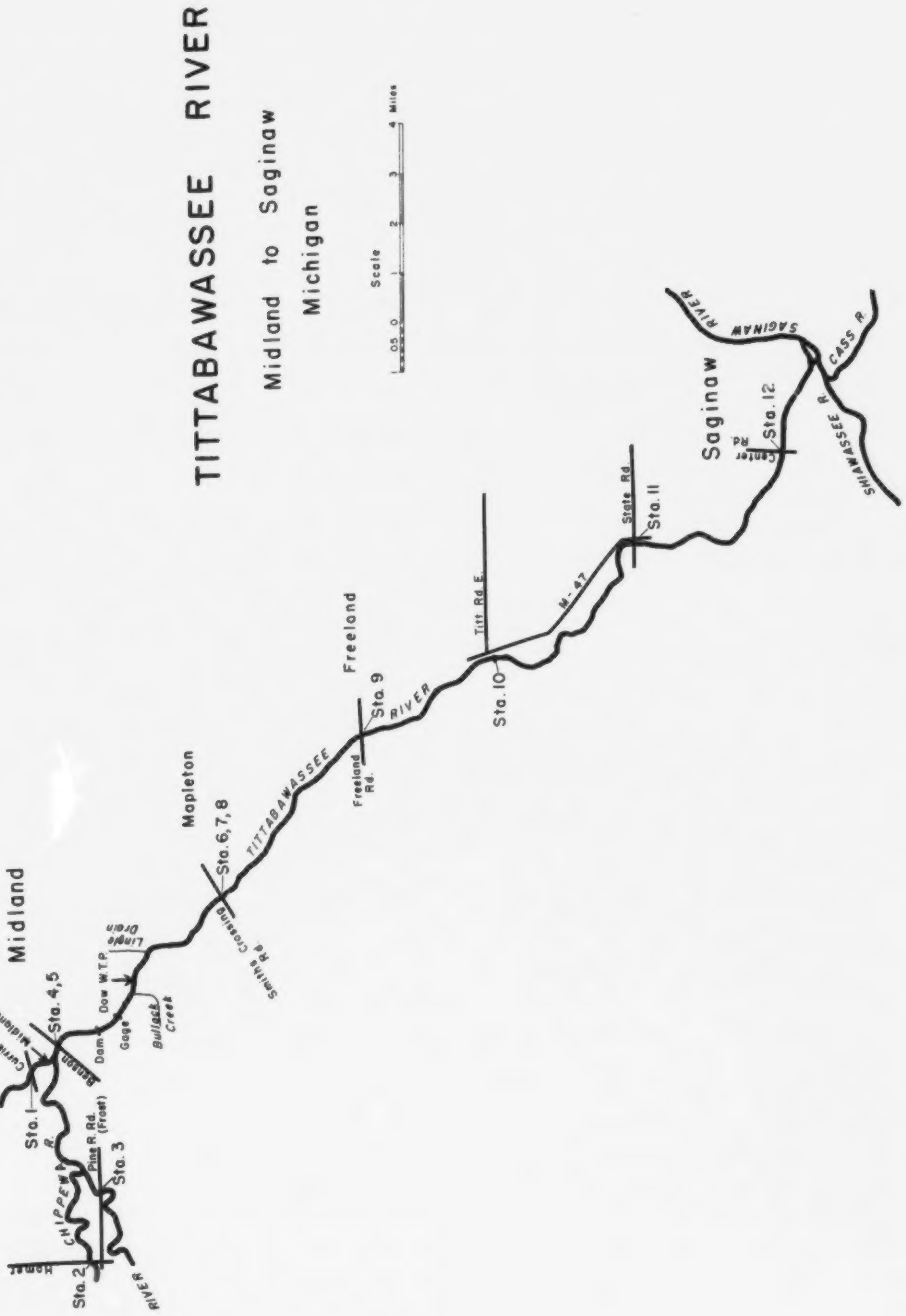

Scale
0 1 2 3 4 Miles
Midland
Mapleton
Freeland
Saginaw
Sta. 1
Sta. 2
Sta. 3
Sta. 4,5
Sta. 6,7,8
Sta. 9
Sta. 10
Sta. 11
Sta. 12
PINE RIVER
CHIPPEWA R.
Homer
Pine R. Rd. (Frost)
Currie Pky
Midland W.T.P.
Benson
Dam
Gage
Dow W.T.P.
Bullock Creek
Lingle Drain
Smiths Crossing Rd.
TITTABAWASSEE RIVER
Freeland Rd.
Titt. Rd. E.
M-47
State Rd.
Center Rd.
SAGINAW RIVER
CASS R.
SHIAWASSEE R.

Figure 4-3

TABLE 4-3

LOCATION OF SAMPLING STATIONS AND OTHER IMPORTANT POINTS

River Mile Point	Location
24.20	City of Midland Waste Treatment Plant Effluent
24.01	Benson St. Bridge in Midland, Stations 4 and 5
23.26	Dow Railroad Bridge
23.15	Dow Dam
22.86	U.S.G.S. Midland Gage on Tittabawassee River
21.77	Dow Waste Treatment Plant Outfall
21.15	Lingle Drain
19.24	Smith's Crossing Bridge, Stations 6, 7, and 8
15.01	Freeland Bridge, Station 9
11.28	West of M-47 by Wading, Station 10
6.69	State Road Bridge, Station 11
2.52	Center Road Bridge, Station 12

River Runoff and Channel Characteristics

Flow in the Tittabawassee River below Midland is measured by a U.S.G.S. continuous recording stream gage located in Midland on the grounds of the Dow Chemical Company. This proved to be a very important gage during the August, 1961 survey period as it is located at the beginning of the critical section of the river under study. Unfortunately, it does not measure the total flow in the river below Midland as a portion of the river is diverted around the gage by the Dow Chemical Company. However, it has been possible through the cooperation of Dow to obtain an accurate measure of the diversions, thereby making it possible to estimate the total river flow below Midland.

During normal low flow periods, pulsations in flow are regularly observed in the Tittabawassee River below Midland as a result of hydropower operations at Sanford Dam upstream from the City. Because it would be difficult to interpret water quality information collected under varying flow conditions, arrangements were made by Dow with the power company to hold the river flow steady and at a reasonably low level for purposes of conducting a water quality survey. A plot of the U.S.G.S. gage chart for the Midland gage for the period August 17 through August 25 is presented as Figure 4-4. It is seen that normal flow conditions illustrating hydropower operations are indicated on August 17 and 18, while special controlled river conditions are shown from the morning of August 23 to the morning of August 25 during the period of intensive river sampling. Thus, it was possible not only to eliminate the hydropower pulsations, but also to establish artificial drought conditions for the survey period.

A U.S.G.S. field crew made a discharge measurement on August 24, 1961 at the Midland gage, making it possible to establish an accurate relationship between gage height and discharge for the survey period.

The flow conditions prevailing during August 23-25, 1961 are summarized in Table 4-4 as follows:

TABLE 4-4

TITTABAWASSEE RIVER FLOW CONDITIONS
August 23-25, 1961

U.S.G.S. Gage at Midland	240 cfs
Diversion by Dow returned to river below U.S.G.S. gage	
Bullock Creek (estimated)	11 cfs
Dow Waste Treatment Plant Effluent	74.4 cfs
Lingle Drain	
Above 84" drain	14.7 cfs
84" drain into Lingle	5.6 cfs
Total Flow in River below Lingle Drain	345.7 cfs

It should be pointed out that a small part of this flow returned by Dow comes from Lake Huron rather than the upper Tittabawassee, thus, constituting a type of flow augmentation.

During part of the survey period it rained intermittently in the lower part of basin, especially in the vicinity of Saginaw,

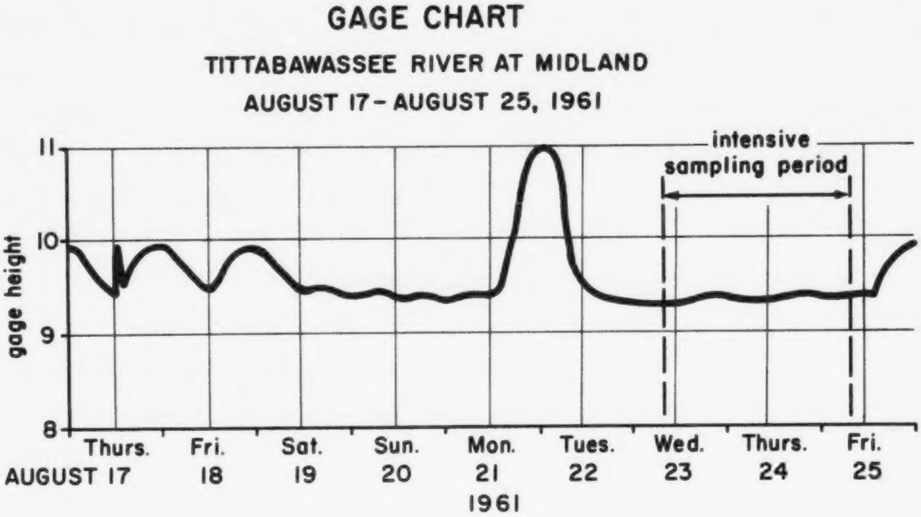


Figure 4-4

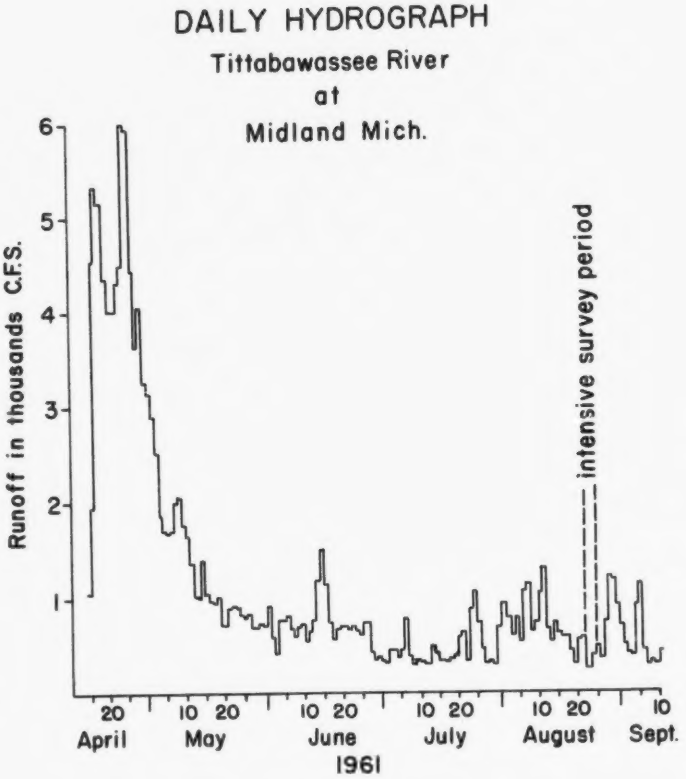


Figure 4-5

but this did not extend above Midland and did not influence the river flow. The main disadvantage was to make conditions uncomfortable for the sampling personnel.

Figure 4-5 is a daily hydrograph for the Midland gage covering the spring and summer period of 1961 preceding the intensive survey period. It is apparent that the artificial low flow conditions established during the survey period were lower than those prevailing during early August and, also, those prevailing after the survey period.

Channel characteristics were available as a result of cross-section work conducted by the staff of the Michigan Water Resources Commission during the period July 30 to August 7, 1957 at 500-foot intervals from Midland to Saginaw. The latest rating curve for the Midland gage was used in making appropriate adjustments of water elevations to a runoff level of 346 cfs prevailing during the survey by the procedure followed by Velz.(2) With this information, it was then possible to calculate river volumes on a displacement basis, which were used in time of passage calculations and in reaeration evaluation.

Generally, the channel is uniform in nature below Midland, with no radical change in cross section, having mean depths ranging between 1.63 and 2.68 feet and widths ranging between 140 and 380 feet with an average of about 250 feet at the runoff level of 346 cfs.

River Temperature Conditions

As a result of the use of Tittabawassee River water for cooling and process purposes, heat is added to the river water causing a rise in temperature to 32.5°C. below Midland. This is contrasted to the temperature range of 20° to 22°C. observed at sampling stations 4 and 5 at the Benson Street bridge in Midland indicating an elevation of water temperature of approximately 10°C. above the normal under the runoff conditions that prevailed during the August, 1961 survey period.

Where river water temperature is elevated above the prevailing equilibrium temperature as a result of the artificial addition of heat, the heat is gradually dissipated to the atmosphere with the resulting decrease in temperature to a level approaching the prevailing equilibrium temperature. A complete discussion of the factors affecting heat dissipation under natural conditions has been presented elsewhere by Velz and Gannon(6) and will not be repeated here. However, the observed temperature profile prevailing during the 1961 survey is presented on a semi-log grid as Figure 4-6, with temperature on the logarithmic scale and time of passage on the linear scale. It is seen that the temperature drops from a level of 32.5°C. below Midland to an average level of 23.6°C. at Center Road sampling station in Saginaw.

Knowledge of river water temperature is important in terms of its influence on the BOD reaction, together with its influence on oxygen saturation capacity in water. Routine water temperature data collected as part of the river sampling program has proven adequate in defining the water temperature variation from Midland to Saginaw.

River Dissolved Oxygen and BOD Relationships

One of the key elements of this research has been a critical evaluation of the relationships that existed during the intensive survey period of August, 1961 between the observed river dissolved oxygen conditions, the observed river BOD conditions, and the BOD rate studies conducted on samples collected of the Dow waste treatment plant effluent, the Tittabawassee River at Smith's Crossing bridge and the Tittabawassee River at Freeland. Here, then, became available an assemblage of information rarely collected in other stream surveys in as comprehensive a manner as this.

Critical inspection of the information early in the analysis period indicated that the dissolved oxygen concentrations were the most sensitive of the measurements taken, followed by routine river 5-day BOD determinations and the special rate studies in this order. As a result, greater reliance has been placed on the dissolved oxygen data than on the BOD information in the analysis that followed.

The observed dissolved oxygen concentrations in the Tittabawassee River below Midland are presented in graphical

OBSERVED RIVER TEMPERATURES

TITTABAWASSEE RIVER
AUGUST 23-25, 1961

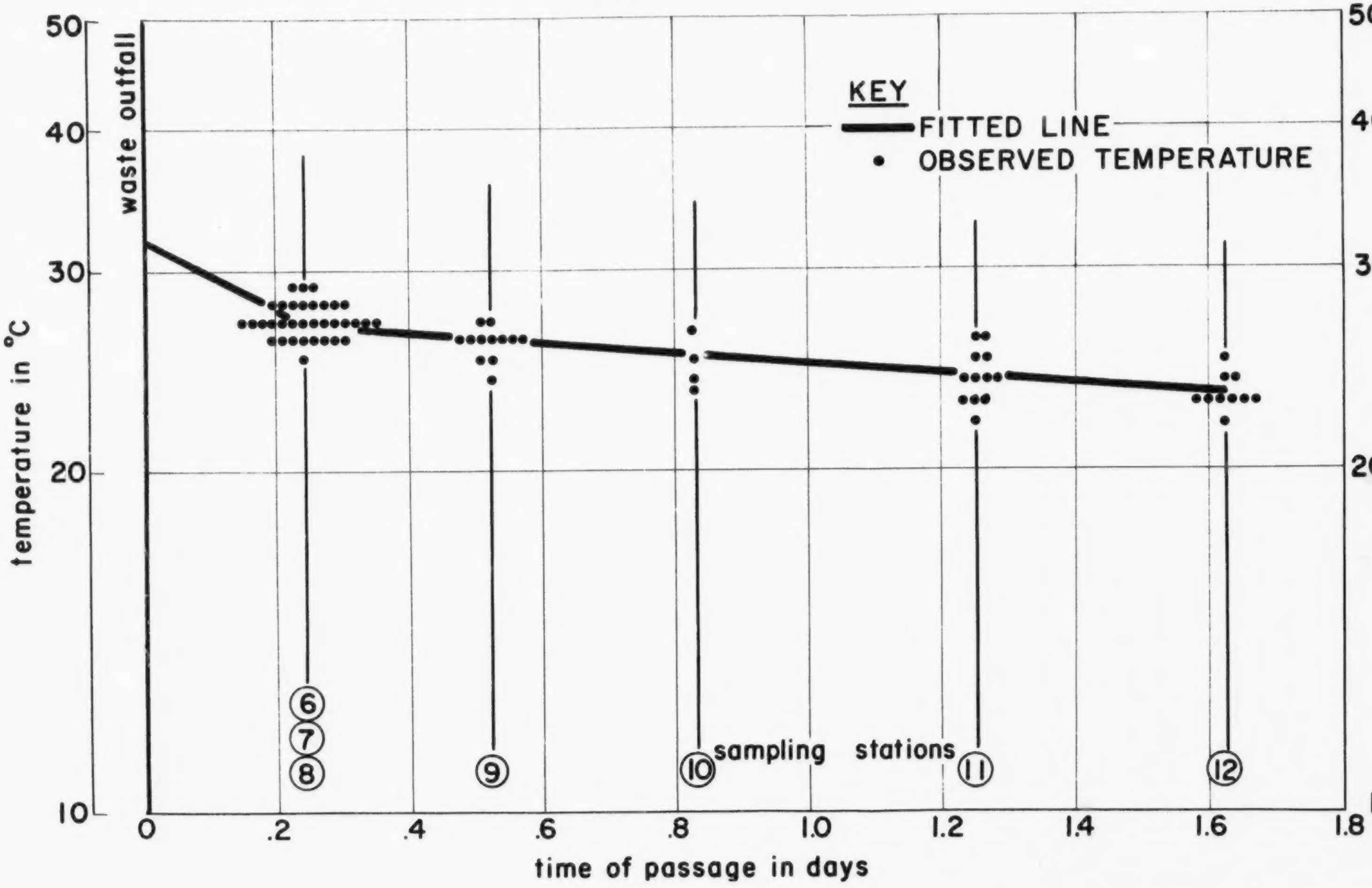


Figure 4-6

form, first, in Figure 4-7 as concentration figures of mg/l and, second, in Figure 4-8 as per cent of saturation. Inasmuch as the temperature conditions are varying through this section, most discussions are in terms of mg/l rather than per cent of saturation. Inspection of Figure 4-7 shows that a definite sag exists below Midland with the low or critical concentration occurring at Station 9 at Freeland bridge. It is seen that the D.O. drops from a mean of approximately 7.5 mg/l at Stations 4 and 5 at Benson Street bridge to a mean low of approximately 4.0 mg/l at Freeland bridge, with one nighttime determination as low as 3.0 mg/l. From here the oxygen concentration recovers to a mean level of 5.5 mg/l at Station 12 at Center Road bridge.

Although no clear-cut distinction exists between day and night samples, it is apparent that the daytime samples are as a group generally higher than the nighttime conditions indicating some photosynthetic influence during the day, notwithstanding the heavy overcast conditions that prevailed throughout the survey period.

The first effort in the analysis of the data consisted of an attempt to independently check the observed dissolved oxygen profile from a consideration of the BOD reductions at the river sampling stations, together with the oxygen assets of runoff and reaeration generally following the methodology suggested by Velz.(7) The advantages of this method of analysis over the conventional oxygen sag equation suggested by Streeter and Phelps(8) is that the observed dissolved oxygen data does not enter into the calculations, but rather, is reserved for independent comparison with the calculated oxygen results.

River BOD reductions might be expressed either in terms of population equivalents or lbs/day of BOD_5, but if expressed in the latter form, a conversion must be made to ultimate BOD before oxygen balances can be calculated. In order to make this conversion, knowledge of the deoxygenation constant k_1 is necessary.

Initial efforts in the analysis of the river BOD information consisted of working in population equivalents, on the assumption that a uniform laboratory k_1 applied to BOD data

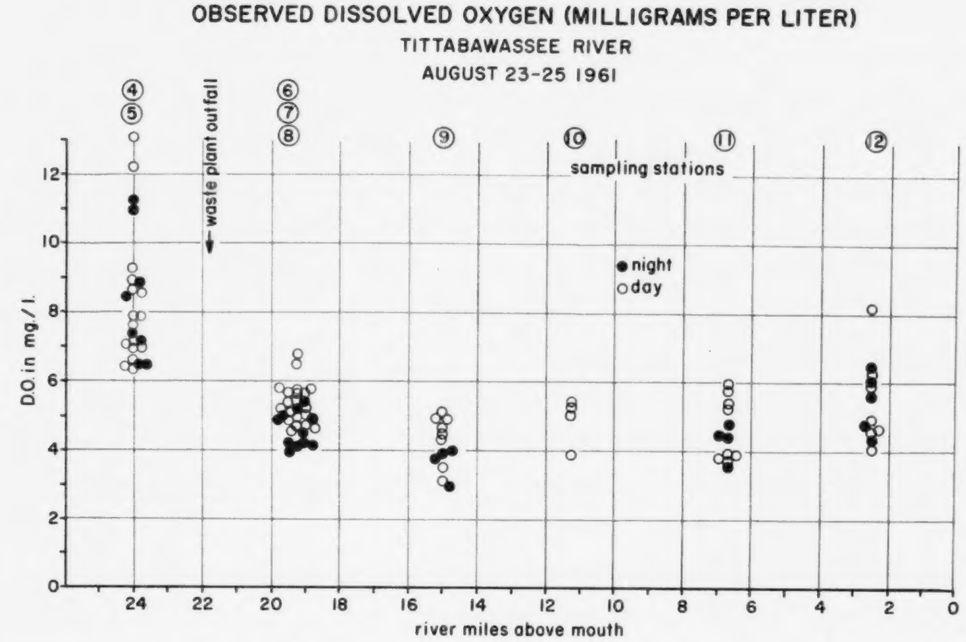


Figure 4-7

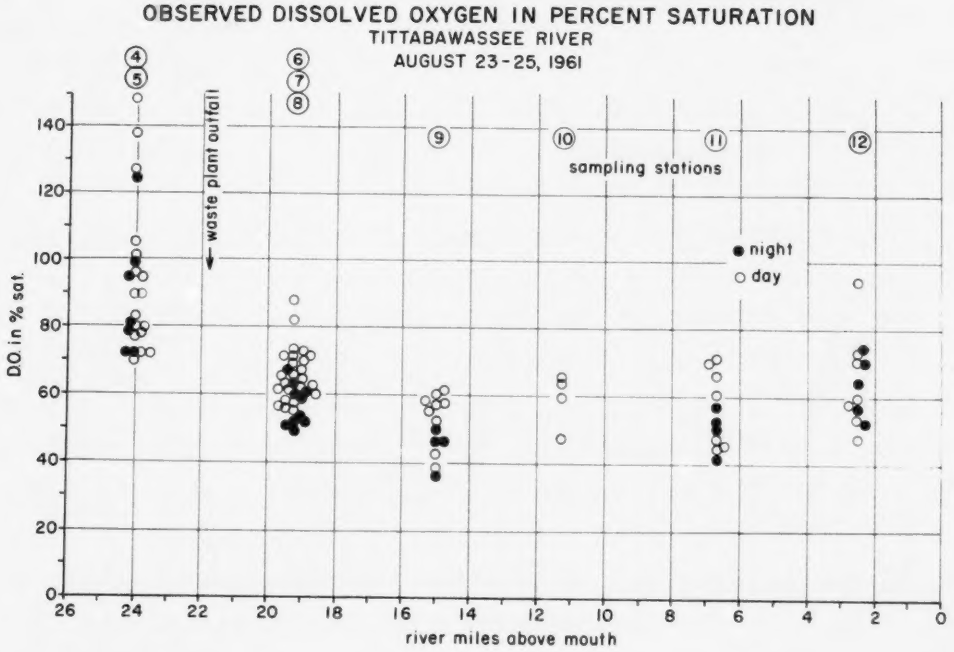


Figure 4-8

collected in the lower river, and that a uniform river k_r applied throughout the critical stretch. Inspection of the routine BOD_5 information indicated that where two incubation dilutions were used, the higher dilution gave consistently higher results, i.e., if a 100 per cent and a 50 per cent dilution were run on a given sample, the 50 per cent dilution gave the higher results. More attention will be devoted to this subject in the section of the report devoted to BOD procedures, but it became apparent that the differences were significant enough to become a matter of major concern. Fortunately, a 50 per cent BOD dilution had been run on every river BOD sample and, therefore, this became the only result used in the river BOD analysis.

A second complicating element developed in the fact that the laboratory k_1 rates determined on the Dow effluent, the Tittabawassee River at Smith's Crossing, and at Freeland did not have the same magnitude. For example, the k_1 rates of the Dow effluent and the Tittabawassee River at Freeland were about 0.02, while the Tittabawassee River at Smith's Crossing was approximately .06. These results will also be discussed more completely in the section of this report which will include a consideration of the influence of the computational method of analysis on the k_1 rate.

After several exploratory calculations along the lines of a uniform laboratory k_1 and a uniform river k_r, a reasonable balance resulted using a laboratory $k_1 = 0.02$ and a river $k_r = 0.194$ from the Dow waste treatment outfall to sampling station 10, and a river $k_r = 0.143$ from here to station 12 at Center Road.

The observed river BOD expressed in population equivalents are plotted in Figure 4-9, with BOD on the log scale versus calculated time of passage on the linear horizontal scale. It is apparent that considerable variation exists among the BOD results at any given sampling station, allowing the investigator considerable latitude in fitting a line through the data. Any minor variation in BOD_5 expressed as a concentration figure in mg/l, makes a big difference when converted to population equivalents because of the relatively large river flow involved. Thus, it is apparent here that the standard BOD_5 procedure as outlined in standard methods(5) is not sensitive enough for the BOD_5 levels

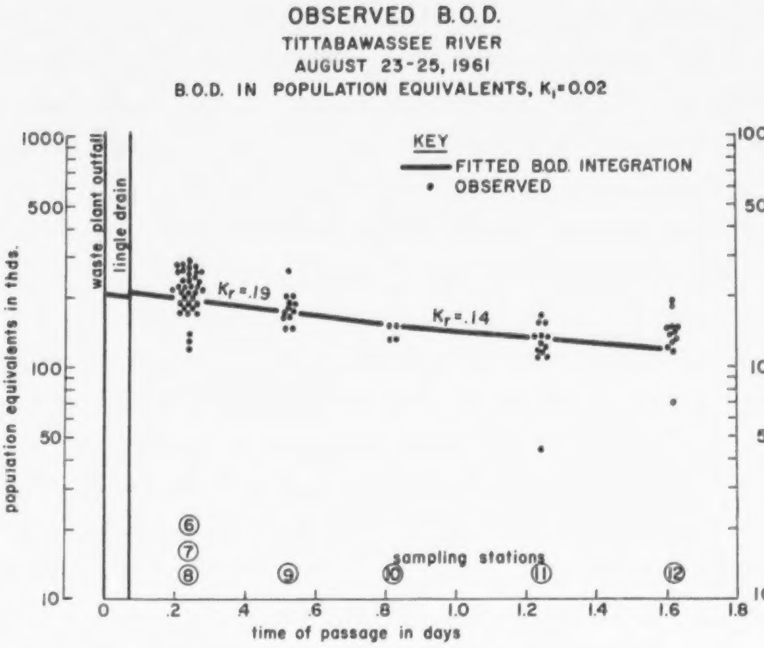


Figure 4-9

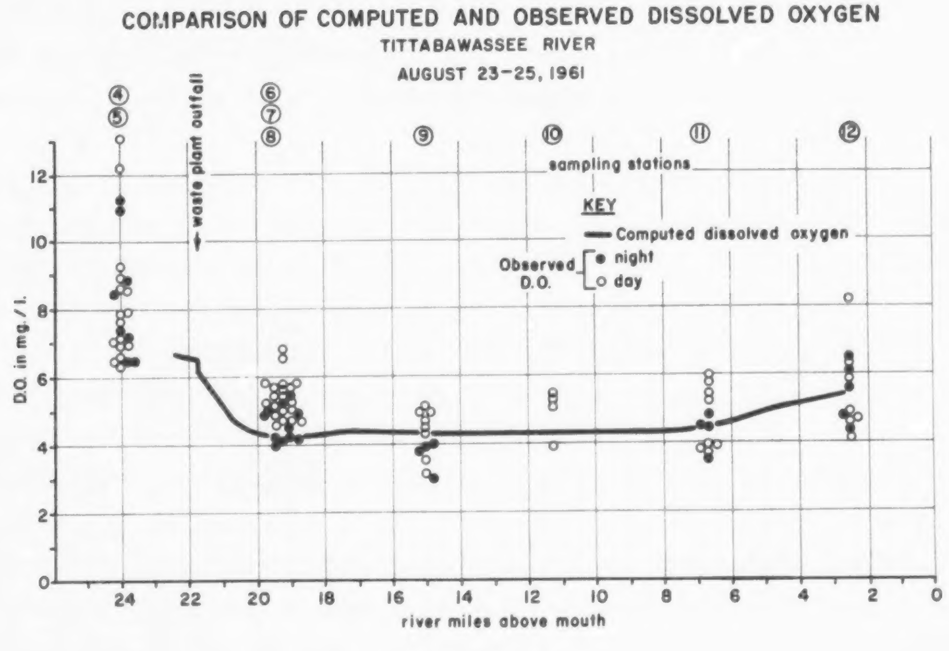


Figure 4-10

observed in the Tittabawassee River. Because of this lack of sensitivity, more reliance has been placed on the dissolved oxygen determination as a measure of water quality.

The BOD_5 results obtained at the two sampling stations in the Tittabawassee River immediately below the Dow treatment plant outfall, when converted to population equivalents using $k_1 = .02$, served as a starting point for the fitted BOD line of Figure 4-9. It is seen the combined loads from the treatment plant and the upstream residuals amounted to 209,000 population equivalents, which is in line with the other river BOD results.

Using the observed BOD drop as indicated by the fitted line of Figure 4-9, the resulting dissolved oxygen profile was calculated using the methodology suggested by Velz.(7) Figure 4-10 shows a comparison of the computed and observed dissolved oxygen profiles during the August, 1961 survey period, indicating good agreement at all stations except at Smith's Crossing bridge where the computed profile passes through the lower part of the observed data. Further discussion of the factors entering into the Velz method of calculating oxygen balance in a river will be presented in the section of this report devoted to programming river dissolved oxygen calculations. In calculating oxygen balances, observed temperatures as presented in Figure 4-6 were used, particularly in the evaluation of oxygen saturation values and reaeration rates.

Recognizing that the assumption of a uniform laboratory k_1 value has not been fully borne out by the available evidence, a second type of analysis has been made starting with the observed dissolved oxygen profile, and working backwards from this and the river k_r data to determine the necessary laboratory k_1 rate.

Figure 4-11 is a plot of the observed river dissolved oxygen values showing a solid line fitted through the estimated mean of the data. In addition to this illustration, Figure 4-12 shows the observed BOD in lbs/day of BOD_5 plotted on a log scale versus calculated time of passage on the horizontal linear scale. Through this observed BOD data, a line has been fitted, corresponding to a river k_r of 0.2 which is seen to be in close agreement with the k_r of 0.194 used in Figure 4-9.

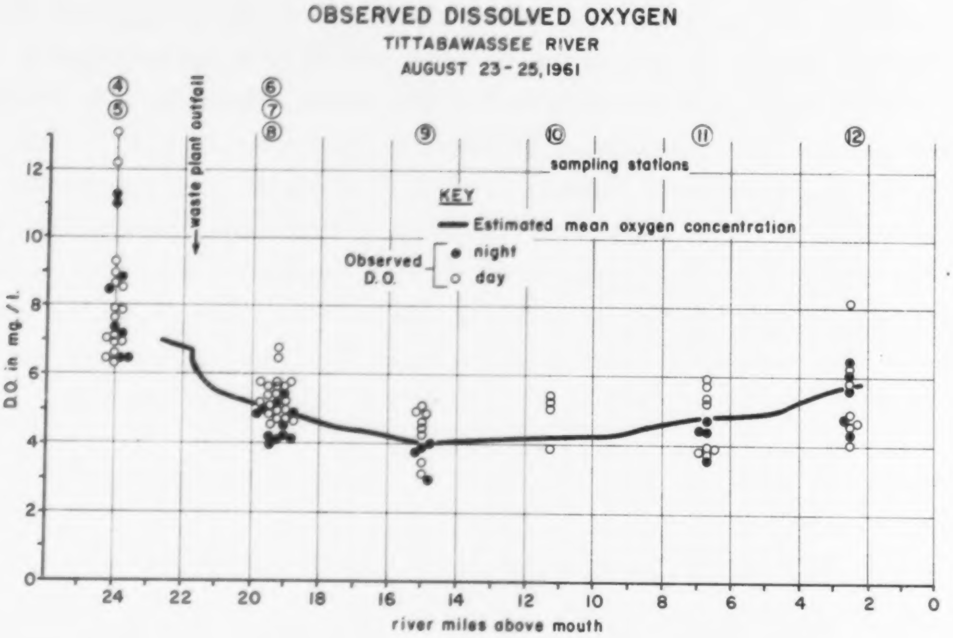


Figure 4-11

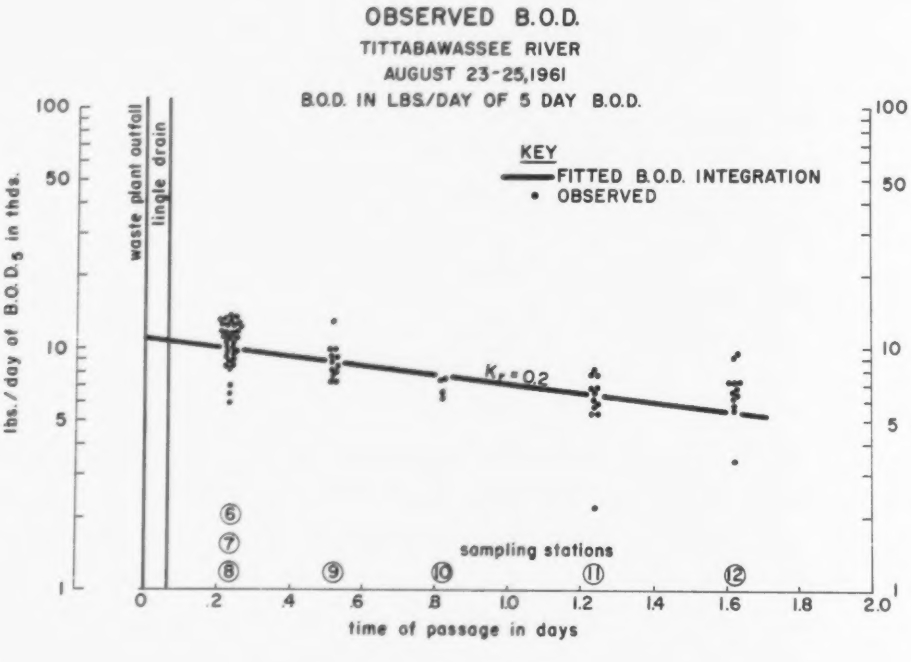


Figure 4-12

Starting with the fitted mean D.O. line of Figure 4-11, it has been possible to work backward to find the necessary ultimate BOD in population equivalents to account for the observed D.O. conditions. Also, using the fitted BOD line of Figure 4-12, it has been possible to determine the mean observed BOD drop between sampling stations expressed in lbs/day of BOD_5. With this BOD_5 information, together with the necessary ultimate population equivalent demand, developed from the observed mean D.O. condition, it has been possible to calculate the necessary laboratory k_1 for each section of the river. The results of this analysis are presented in Table 4-5 as follows where the conversion figure of 0.24 lbs/day of ultimate BOD equal to one population equivalent has been used:

TABLE 4-5

CALCULATED LABORATORY k_1 TO CHECK OBSERVED RIVER CONDITIONS

M.P.	Station	Necessary P.E. to Check D.O. of Fig 4-11	Observed lbs/day BOD_5 from Fig 4-12	lbs/day BOD_5 drop between Station	Calculated k_1 for Section
21.77	Dow Outfall		10,800		
		15,958		800	.0204
19.24	Smith's Crossing		10,000		
		31,443		1,200	.015
15.01	Freeland		8,800		
		21,532		1,100	.0208
11.28	Station 10		7,700		
		13,760		1,300	.0434
6.69	State Road		6,400		
		12,782		950	.034
2.52	Center Road		5,450		

Taking the calculated k_1 values of the last column of Table 4-5 and weighting them in accordance with distance, gives an overall weighted k_1 for the section of the river from M.P. 21.77 to M.P. 2.52 of 0.0276. This, it is seen, is in good agreement with the k_1 used in calculating the population equivalents of Figure 4-9 and, also, with the laboratory k_1 rates independently determined on samples of the Dow effluent and the Tittabawassee River at Freeland.

A second series of calculations along these same lines was performed using observed time of passage information collected by means of dye tracers, under controlled river conditions in August, 1962, rather than the calculated times heretofore used. The runoff levels in 1962 were of the order of 316 cfs rather than 346 cfs observed in 1961 resulting in slight differences of times. Notwithstanding these differences, the calculated k_1 values were extremely close to those listed in the last column of Table 4-5. Further discussion of comparisons of the calculated and obsered times of passage using dye tracers will be presented more fully in another section of this report.

It is important to appreciate the significance of the laboratory k_1 rate in converting observed BOD information, available in lbs/day BOD_5, to an ultimate expression of first stage demand, either in terms of lbs/day BOD, ultimate, or to population equivalents. For example, if the Dow treatment plant effluent had a BOD_5 of 3.6 mg/l in a flow of 48 MGD, it would have a load of 1,441 lbs/day BOD_5. Using this figure, it is seen that for a laboratory $k_1 = 0.1$ the resulting ultimate load would be 8,790 population equivalents, for a laboratory $k_1 = .06$ the ultimate load would be 12,060 population equivalents, for a laboratory $k_1 = .04$ the ultimate load would be 16,300 population equivalents, while for a laboratory $k_1 = .02$ the ultimate load would be 29,230 population equivalents. Thus, for this k_1 range the ultimate load could vary from 8,790 population equivalents to 29,230 population equivalents. In characterizing a waste load, therefore, in terms of its effect on the river, it is important to know not only the BOD_5 and the corresponding flow, but also, its laboratory k_1 rate.

It is apparent from what has been presented that the river $k_r = 0.2$ is approximately ten times the laboratory $k_1 = 0.02$; the question might be raised--Why is this? Is there an adequate explanation to account for this difference such as sludge deposits or possibly biological extraction and accumulation as reported occurring in several rivers by Velz and Gannon?(9) Velz(2) in an analysis of Tittabawassee stream survey data collected in 1957 found a river $k_r = 0.386$ and a laboratory

$k_1 = 0.06$, attributing the river k_r to the phenomena of biological extraction and accumulation, resulting from activated floc carried to the river because of hydraulic overloading of the Dow waste treatment plant. As a result of the Velz study and report, Dow improved the operating efficiency of their waste treatment plant by various internal adjustments so that the effluent BOD_5 during the August, 1961 survey period was extremely low, with no visible solids present. It can be assumed, therefore, that because of this improvement the k_1 dropped from 0.06 to 0.02 and, also, the river k_r dropped from 0.386 to approximately 0.2.

During the 1961 survey period, the writer made a careful field inspection by boat of the section of the Tittabawassee River from Smith's Crossing bridge to the Dow treatment plant outfall. As part of the inspection trip, frequent bottom and plankton samples were collected for later microscopic examination in the laboratory. When these examinations were completed, no unusual organisms were noted such as Sphaerotilus natans which is frequently associated with river biological extraction. Moreover, none of the bottom samples showed evidence of organic deposits nor were there any sludge deposits noted during the field inspection, itself. Thus, based on this information, the influence of extensive sludge deposits or observable active biological extraction on the river k_r during the August, 1961 survey period must be ruled out. It can be assumed, therefore, that certain natural conditions found in the river such as turbulence, etc., is causing a much faster oxidation rate than can be developed in the laboratory under standard conditions of quiescence and darkness.

In the analysis procedure followed, heavy reliance has been placed on the accuracy of the reaeration calculations following the procedures of Velz.(7) It is the feeling of the writer that the Velz method is a sound one having been successfully applied to many practical river situations since it was proposed in 1939. Certain of the empirical components, especially the time of mix relationships, have been adequately defined for the ranges ordinarily found in river situations. In recent years, O'Connor and Dobbins(10) and also, Churchill(11) have proposed similar methods of reaeration calculation employing mean river depth and velocity.

As a result of the information collected under the August, 1961 survey conditions, including the subsequent analysis of the data, no strong evidence became available to support the major hypothesis of this study, i.e., a high k_r is due to some abnormality such as sludge deposition or biological extraction or accumulation. While some abnormality could have been present that might not have been recognized, it appears more logical to assume that BOD reduction between sampling stations was due to an increased oxidation rate in the river over that developed under standard laboratory conditions.

SUMMARY AND CONCLUSIONS

This section of the report has been concerned with the presentation of data and a discussion of results relating to the 1961 survey conducted on the Tittabawassee River between Midland and Saginaw, Michigan. BOD removal rates in the river were high with a k_r of approximately 0.2, while the k_1 of the river and effluent samples were of the order of approximately 0.02. Of the measurements taken, the dissolved oxygen concentrations were the most sensitive, followed by routine river 5-day BOD determinations, and the special rate studies in this order. As a result, greater reliance has been placed on the dissolved oxygen data than on the BOD information.

No strong evidence became available to support the major hypothesis of the study, and it appears more logical to assume that BOD reduction between sampling stations was due to an increased oxidation rate in the river over that developed under standard laboratory conditions.

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SECTION V

BOD RATE SUMMARIES

In support of the intensive river water quality surveys conducted on both the Clinton and Tittabawassee Rivers, a large number of BOD rate studies were conducted on both effluent samples and selected river water samples to reflect seasonal variation, temperature variation, mixing vs. non-mixing, and the influence of carrying on rate studies for extended periods of one to three months. During the period of this investigation, some 208 BOD rates were run on Clinton River water and Pontiac waste treatment plant effluents, together with 139 BOD rates on Tittabawassee River water and Dow waste treatment plant effluent, making a total of 347 rates.

As will be discussed more fully in the next section of this report, major reliance has been placed on the reaeration technique as proposed by Elmore,(1) which was used in all cases except as noted, although selected comparisons have been made with the standard dilution procedure by running samples in parallel using both techniques. This section of the report will present the results in summary form for both the Clinton and Tittabawassee River rate studies including seasonal variation, temperature variation, mixing vs. non-mixing, and long term rates.

Clinton River

Seasonal Variation

For purposes of reflecting seasonal variation in both BOD_5 level and k_1 rate, samples were collected at least monthly for rate analysis at selected stations on the Clinton River. Because water quality conditions were generally poorer in the summer due to high temperatures and low runoff, samples were collected more frequently during this time. Figures 5-1, 5-2, and 5-3 are daily hydrographs for the Clinton River at the Auburn Heights gage for the years 1960, 1961, and 1962, with the routine sampling days indicated across the top of each hydrograph, allowing quick visual comparison between the sampling day, the season of the year, and the runoff prevailing before and during each sampling day. Also, the intensive

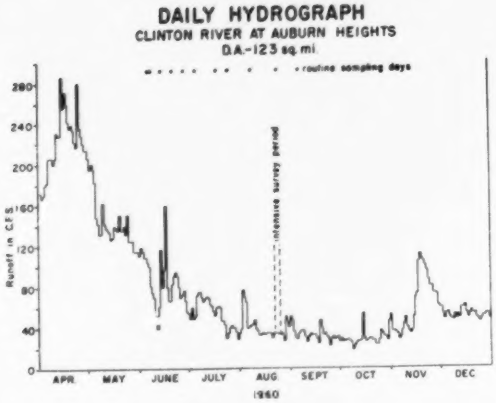


Figure 5-1

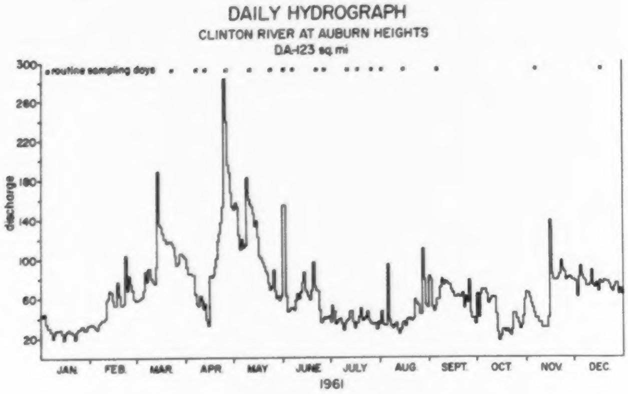


Figure 5-2

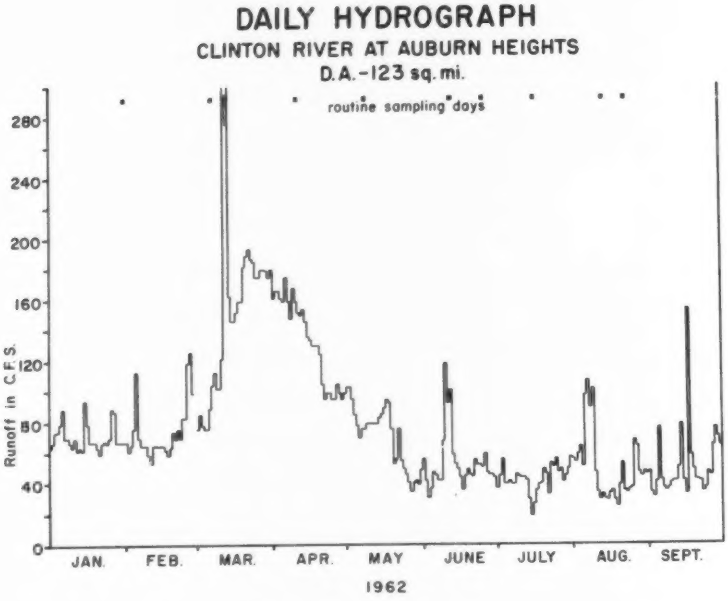


Figure 5-3

sampling period of August 23-25, 1960 is indicated on the 1960 daily hydrograph.

Tables 5-1A and 5-1B are a summary of the results for the selected sampling stations indicating the BOD_5 in mg/l and the k_1 obtained for the first five days of the rate study. More complete rate summary data is presented in Appendix I-B of this report.

Inspection of the results presented in Tables 5-1A and 5-1B indicates that no seasonal pattern of either BOD_5 or k_1 exists in the Clinton River, particularly in the section below the point where the Pontiac effluent enters the river. Almost all of the k_1 values in this section are of the order of 0.01 or less, due to the influence of the plant effluent. In contrast, it is seen that the k_1 values of the river samples collected from the plant bridge (station 1) upstream from the effluent discharge point tended to cluster about the more normal value of $k_1 = 0.10$, with one value as low as 0.01, and one value as high as 0.23.

Temperature Variation

In order to evaluate the influence of temperature, selected effluent and river water samples were divided into three parts, with simultaneous BOD rates run on each part at a different temperature. During the summer of 1960, the incubation temperatures were 37°C, 20°C, and 13°C, while during the winter period of 1961-1962, the Auburn Heights samples were incubated at temperatures of 30°C, 20°C, and the actual river water temperature at the time of collection. Thus, in the latter instance the lower incubation temperature was variable, ranging from a low of 0.25°C for the January 31, 1962 sample, to a high of 17.5°C for the May 9, 1962 sample.

Table 5-2 is a summary of the results for the selected sampling stations indicating the BOD_5 in mg/l and the k_1 obtained for the first five days of the rate study. More complete rate summary data is presented in Appendix I-B of this report.

Inspection of the results presented in Table 5-2 for the July 6 and July 19, 1960 samples indicates that generally the k_1 rate for the 37°C samples is higher than either the 20°C or 13°C samples, but the BOD_5 at 37°C for those samples involving either

TABLE 5-1A

ROUTINE BOD RATE SUMMARIES, CLINTON RIVER, 1960-1962

BOD_5 in mg/l and k_1 for first 5 days of rate

Incubation Temperature 20°C.

Year	Date	Beaudette		Plant Br. (Sta. 1)		Pontiac T.F.		Pontiac A.S.	
		BOD_5	k_1	BOD_5	k_1	BOD_5	k_1	BOD_5	k_1
1960	6-7			8.8	.06				
	6-9								
	6-22			6.7	.14				
	6-29			3.8	.03				
	7-6			4.7	.07				
	7-19	2.4	.07	4.4	.11				
	7-26	2.4	.05	3.4	.08				
	8-9								
	8-25								
1961	1-5								
	3-23							14.7	<.01
	4-7					32.5	.13		
	4-13							5.6	.06
	4-26							11.8	.05
	5-11			4.2	.05			11.0	.07
	5-24							13.4	<.01
	6-22			3.6	.08				
	6-27			3.1	<.01				
	7-12			5.9	.13			10.7	<.01
	7-18					20.4	<.01	6.6	<.01
	7-27								
	8-2								
	8-16			2.7	.17				
	9-6								
	11-7			3.4	.23			8.2	.02
	12-18			1.8	.14			8.4	<.01
1962	1-31	1.5	.16	1.5	.16				
	3-7			2.6	.12			6.8	<.01
	4-11			3.4	.09			17.2	<.01
	5-9			4.0	.09			11.4	<.01
	6-13			7.4	.07			11.6	<.01
	6-26								
	7-17			4.1	.10			5.2	<.01
	8-14							13.1	<.01
	8-23							7.3	<.01

TABLE 5-1B

ROUTINE BOD RATE SUMMARIES, CLINTON RIVER, 1960-1962

BOD$_5$ in mg/l and k_1 for first 5 days of rate

Incubation Temperature 20°C

Year	Date	Opdyke		M-59		Auburn Hts.		Adams	
				(Sta. 2)		(Sta. 3)		(Sta. 6)	
		BOD$_5$	k_1	BOD$_5$	k_1	BOD$_5$	k_1	BOD$_5$	k_1
1960									
	7-6			8.7	<.01				
	7-19	8.7	<.01					6.2	<.01
	7-26	*11.3	<.01					7.1	<.01
	8-9			*12.8	<.01				
	8-25					6.3	<.01		
1961									
	1-5					16.3	.06	13.8	<.01
	6-22					5.9	<.01		
	6-27			10.2	<.01	4.4	.10		
	7-12			14.8	<.01				
	7-18			10.1	.02	3.8	<.01	7.1	<.01
	7-27			13.4	<.01	4.0	<.01	7.6	<.01
	8-2					12.8	<.01	13.5	<.01
	8-16					4.0	<.01	6.7	<.01
	9-6					10.2	<.01		
	11-7					6.1	<.01	7.6	<.01
	12-18					5.6	<.01	5.2	<.01
1962									
	1-31					3.9	<.01	5.0	.03
	3-7					2.7	<.01	6.7	<.01
	4-11					4.2	<.01	5.6	<.01
	5-9					9.4	<.01	6.5	<.01
	6-13					5.6	<.01	8.3	<.01
	6-26					*16.5	<.01		
	7-17							9.4	<.01
	8-14					2.5	<.01	6.4	<.01
	8-23					3.6	.03	8.6	<.01

*Average of Replicates

TABLE 5-2

BOD RATE SUMMARIES, CLINTON RIVER, 1960-1962

Temperature Influence

Date	Beaudette			Plant Br. (Sta. 1)			Pontiac WTP			Opdike			M-59 (Sta. 2)			Auburn Hts. (Sta. 3)			Adams (Sta. 6)		
	°C	BOD_5	k_1	°C	BOD_5	k_1	°C	BOD_5	k_1	°C	BOD_5	k_1	°C	BOD_5	k_1	°C	BOD_5	k_1	°C	BOD_5	k_1
1960 7-6				20	4.7	.07	20	28.3	.02				20	8.7	<.01						
				37	6.9	.12	37	7.8	.15				37	6.4	.14						
				13	2.8	.04	13	17.4	< .01				13	3.5	<.01						
7-19	20	2.4	.07	20	4.4	.11				20	8.6	<.01							20	6.2	<.01
	37	3.2	.16	37	6.5	.22				37	6.7	.14							37	4.4	.15
	13	1.3	.07	13	3.2	<.01				13	3.8	<.01							13	2.0	<.01
1961 8-2																20	12.8	<.01	20	13.5	<.01
																33	18.8	.02	33	16.0	.07
																10	5.3	<.01	10	3.8	<.01
12-18																20	5.6	<.01			
																30	12.3	<.01			
																2.5	.2	--			
1962 1-31																20	3.9	<.01			
																30	14.9	<.01			
																.25	.4	--			
3-7																20	2.7	<.01			
																30	6.3	<.01			
																4	.2	--			
4-11																20	4.2	<.01			
																30	9.7	<.01			
																8	1.3	.07			
5-9																20	9.4	<.01			
																30	17.9	<.01			
																17.5	8.7	<.01			
6-13																20	5.6	<.01			
																30	14.8	<.01			
																	--	--			

the treatment plant effluent or river water including the effluent is lower than the 20°C BOD_5. Inasmuch as nitrification is known to be present, it might be assumed that at 37°C nitrification has been inhibited, which was not the case at 20°C. Unfortunately, no specific evidence is available to support this assumption.

In contrast to the summer, 1960 samples, it is seen that the winter 1961-1962 information more closely follows the expected pattern, with the higher BOD_5 observed for the 30°C samples, and the lowest BOD_5 for the river water temperature incubation. However, very little variation was noted in the k_1 values with the majority in the range of 0.01 or less.

Mixing vs. Non-Mixing

The standard BOD procedure calls for running the test under quiescent conditions which, of course, is radically different from the normal conditions of turbulence which prevail in a natural stream. To more closely approximate the natural conditions, selected BOD rates were run under continuous mixing in sealed BOD bottles, with mixing supplied by means of magnetic stirrers.

Table 5-3 is a summary of the results for Pontiac activated sludge effluent and the Auburn Heights sampling station, indicating the BOD_5 in mg/l and the k_1 obtained for the first five days of the rate study. More complete rate summary data is presented in Appendix I-B of this report.

Inspection of the results presented in Table 5-3 indicates that in most cases mixing caused both a higher k_1 and BOD_5 over that determined on the non-mixed sample. This strongly suggests, therefore, that the natural conditions of turbulence found in a stream do accelerate the BOD reaction, but it is doubtful, as has been previously discussed, that this is the only factor contributing to the high $k_r = 1.1$ found in the Clinton River.

Long Term Rates

Selected samples of both the Pontiac effluent and Clinton River water were incubated for varying periods of time beyond the usual period of 7 to 14 days, with one sample of river water collected on August 14, 1962 at the Auburn Heights sampling station incubated for 166 days.

TABLE 5-3

BOD RATE SUMMARIES, CLINTON RIVER, 1961

Mixing vs. Non-Mixing

Standard Incubation Temperature, 20°C

Date	Pontiac A.S.			Auburn Heights		
		BOD_5	k_1		BOD_5	k_1
3-23-61	M	18.2	.14			
	NM	14.7	<.01			
4-13-61	M	10.5	.13			
	NM	5.6	.06			
4-26-61	M	15.2	.14			
	NM	11.8	.05			
5-11-61	M	12.5	.10			
	NM	11.0	.07			
5-11-61	M*	10.9	.11			
	NM*	8.7	.04			
5-24-61	M	24.0	<.01			
	NM	13.4	<.01			
6-7-61	M	17.7	<.01			
	NM	16.5	<.01			
6-7-61	M*	13.7	<.01			
	NM*	7.2	<.01			
6-22-61				M	7.8	.09
				NM	5.9	<.01
7-27-61				M	8.8	.11
				NM	4.0	<.01

*50% Effluent and 50% River Water.

Table 5-4 is a summary of the results for the selected samples, indicating among other things the k_1 obtained from the first five days of observations, together with a k_1 calculated from BOD_5 and BOD_{final}, assuming that the latter figure represents the ultimate BOD. Inasmuch as the BOD rates were conducted over varying periods of times, the k_1 values presented in the last column of Table 5-4 are not directly comparable but are presented

TABLE 5-4

BOD RATE SUMMARIES, CLINTON RIVER, LONG TERM RATES

Incubation Temperature, 20°C

Station	Date of Collection	Rate Duration Days	k_1 for First 5 Days	BOD_5 mg/l	BOD Final mg/l	BOD_5 as % of BOD Final	k_1 from BOD_5 and BOD Final
Beaudette Park Bridge	7-19-60	40.91	.07	2.37	6.78	35.0	.037
	7-26-60	84.91	.05	2.39	10.40	23.0	.023
Plant Bridge (Sta. 1)	6-7-60	75.45	.06	8.81	24.56	35.9	.039
	7-6-60	34.85	.07	4.66	12.67	36.8	.040
	7-19-60	40.88	.11	4.44	11.85	37.5	.041
	7-26-60	84.90	.08	3.45	11.60	29.7	.031
Pontiac Activated Sludge Effluent	6-9-60	53.58	<.01	20.16	39.62	50.9	.062
	4-11-62	27.69	<.01	17.18	59.75	28.8	.030
	8-14-62	145.53	<.01	13.13	59.65	22.0	.022
Grand Trunk Railroad Bridge	6-7-60	69.47	.07	9.17	36.27	25.3	.025
Auburn Heights (Sta. 3)	8-25-60	24.83	<.01	6.33	24.86	25.5	.026
	8-14-62	166.50	<.01	2.47	53.96	4.6	.004
Adams St. Bridge (St. 6)	7-19-60	30.61	<.01	6.23	14.14	44.1	.051
	7-26-60	54.85	<.01	7.12	20.95	34.0	.036
	9-7-60	41.92	<.01	7.79	14.40	54.1	.068

as a matter of information. Also, the BOD figures presented in Table 5-4 represent total oxygen utilized, with no attempt made to distinguish between the carbonaceous and nitrogenous demands.

Inspection of typical time vs. BOD plots on a linear scale for these long term rates generally shows a period of relatively rapid oxygen utilization lasting about 10 days, followed by a series of oxygen plateaus of little oxygen utilization, lasting in some cases as long as a month or more. After each stabilized period, there is another period of oxygen utilization coming to a subsequent plateau. Thus, no level was reached of complete stabilization as suggested in the classical BOD reaction, not even in the case of the sample incubated for 166 days.

The question might be raised--Is there an explanation for this? Careful attention has been given to laboratory technique suggesting a minimal opportunity for external contamination of the container, although it is possible that with time, there is a readjustment of the internal microorganism population resulting in the breakdown of materials not previously broken down. A second possible explanation is that the more complex compounds are broken down with time into simpler compounds, which then become available for biochemical oxidation.

TITTABAWASSEE RIVER

Seasonal Variation

For purposes of reflecting seasonal variation in both BOD_5 level and k_1 rate, samples were collected at least monthly for rate analysis at selected stations on the Tittabawassee River. Because better study conditions existed in the summer due to high temperatures and low runoff, samples were collected more frequently during this time. Figures 5-4, 5-5, and 5-6 are daily hydrographs for the Tittabawassee River at the Midland gage for the years 1960, 1961, and 1962, with the routine sampling days indicated across the top of each hydrograph, allowing quick visual comparison between the sampling day, the season of the year, and the runoff prevailing before and during each sampling day. Also, the intensive sampling period of August 23-25, 1961 is indicated on the 1961 daily hydrograph.

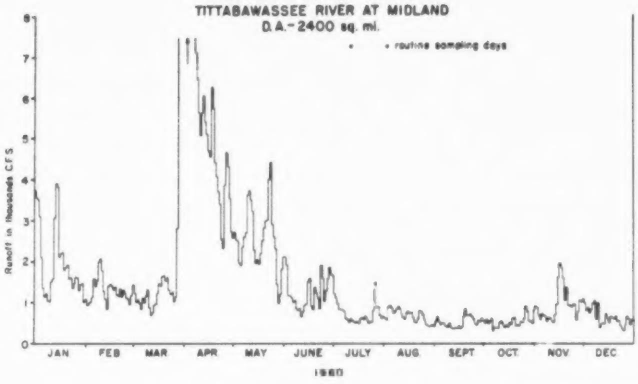


Figure 5-4

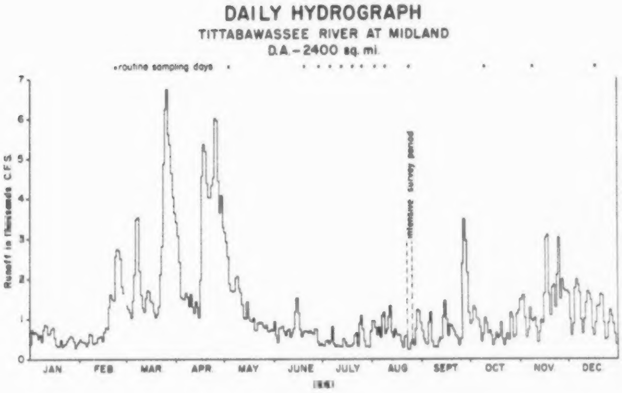


Figure 5-5

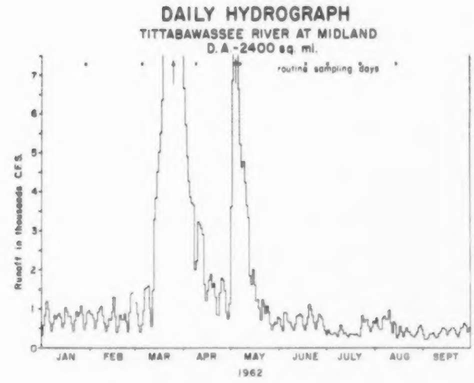


Figure 5-6

Table 5-5 is a summary of the results for the selected sampling stations indicating the BOD_5 in mg/l and the k_1 obtained for the first five days of the rate study. More complete rate summary data is presented in Appendix II-B of this report.

Inspection of the results presented in Table 5-5 indicates that no seasonal pattern of either BOD_5 or k_1 exists in the Tittabawassee River, particularly at the sampling stations below Midland. Considerable variation exists among the k_1 rates, especially those for samples collected at the Smith's Crossing and Freeland sampling stations. It is to be noted, however, that most of the k_1 rates at these stations are less than 0.1, but generally above 0.01. These values are to be contrasted, therefore, with the rather consistent $k_1 = 0.01$ or less values observed in the case of Clinton River water samples.

Temperature Variation

In order to evaluate the influence of temperature, selected effluent and river water samples were divided into three parts, with simultaneous BOD rates run on each part at a different temperature. During the summer of 1961, the incubation temperatures were $33^{\circ}C$, $20^{\circ}C$, and $10^{\circ}C$, while during the winter period of 1961-1962, the Smith's Crossing samples were incubated at temperatures of $30^{\circ}C$, $20^{\circ}C$, and the actual river water temperature at the time of collection. Thus, in the latter instance the lower incubation temperature was variable, ranging from a low of $3.5^{\circ}C$ for the January 29, 1962 sample, to a high of $15.5^{\circ}C$ for the May 7, 1962 sample.

Table 5-6 is a summary of the results for the selected sampling stations indicating the BOD_5 in mg/l and the k_1 obtained for the first five days of the rate study. More complete rate summary data is presented in Appendix II-B of this report.

Inspection of the results presented in Table 5-6 indicates that no consistent pattern developed as far as temperature influence is concerned, either in terms of BOD_5 level or k_1 level. During the winter period 1961-1962, the Smith's Crossing samples more nearly followed the expected pattern, with the higher BOD_5

TABLE 5-5

BOD RATE SUMMARIES, TITTABAWASSEE RIVER, 1960-1962

Incubation Temperature, 20°C

Date	Currie (Sta. 1)		Benson (Sta. 4,5)		Dow Effluent		Smith's (Sta. 6,7,8)		Freeland (Sta. 9)		State Street (Sta. 11)	
	BOD_5	k_1	BOD_5	k_1	BOD_5	k_1	BOD_5	k_1	BOD_5	k_1	BOD_5	k_1
7-12-60					4.8	.05	3.8	.09				
8-3-60			4.4	.07	4.7	.03	3.0	.03	3.2	.09		
2-23-61			3.0	.07	7.0	<.01	4.2	.10	5.1	.02		
5-4-61					9.7	.14						
6-20-61	1.6	.16					3.1	.08	2.6	.19		
6-29-61	1.3	.04			5.8	.05	3.7	.02				
7-6-61	1.8	<.01			6.2	<.01	3.3	<.01	3.6	.07		
7-13-61	1.1	.08					4.2	<.01				
7-20-61	3.0	.08			7.5	<.01	4.6	.11	5.0	.22		
7-26-61					29.6	<.01	17.5	<.01	24.4	<.01		
8-3-61	2.5	.04			6.2	<.01	3.8	.05	3.9	.05		
8-9-61	3.8	<.01			2.7	.02	3.2	.07	3.3	.07		
8-24-61	1.8	.02					3.1	.07	2.6	<.01		
10-10-61			2.6	.10	5.5	<.01	2.9	.10	2.1	.03		
11-9-61					6.3	<.01	3.1	.10	2.4	.06		
12-18-61			1.6	.02	5.8	<.01	1.6	<.01	2.8	.11		
1-29-62			1.5	<.01	6.4	.03	4.5	<.01	4.9	.01		
3-5-62					10.7	.04	5.7	<.01	4.6	<.01	3.6	<.01
4-9-62			1.4	.05	6.6	<.01	2.3	.01	3.2	.06		
5-7-62			N1.9	.08								
			S1.9	<.01	9.2	<.01	2.1	.01	2.3	<.01		
6-18-62			3.5	.16	54.6	.02	17.0	.18	3.1	.08		
7-2-62					4.0	<.01	*3.3	<.01				
7-23-62			4.0	.06	2.7	<.01	2.0	<.01	2.5	<.01		
8-15-62					2.3	.05	2.1	.08	1.7	.07		

*Average of replicates

TABLE 5-6

BOD RATE SUMMARIES, TITTABAWASSEE RIVER, 1961-1962

Showing Temperature Influence

Date	Dow			Smith's			Freeland		
	°C	BOD$_5$	k$_1$	°C	BOD$_5$	k$_1$	°C	BOD$_5$	k$_1$
7-13-61	20	5.1	.07	20	4.2	<.01			
	33	10.2	.03	33	8.5	.10			
		--	--		--	--			
7-26-61	20	29.6	<01	20	17.5	<.01	20	24.4	<.01
	33	12.3	<.01	33	6.7	.12	33	5.3	.24
	10	1.4	.03	10	.8	.20	10	1.5	<.01
8-9-61	20	2.7	.02	20	3.2	.07			
	33	7.9	<.01	33	6.6	.13			
		--	--		--	--			
8-24-61				20	3.1	.07			
				33	1.0	<.01			
					--	--			
12-18-61				20	1.6	<.01			
				30	2.0	.07			
				4	.13	--			
1-29-62				20	4.5	<.01			
				30	6.2	.11			
				3.5	.5	<.01			
3-5-62				20	5.7	<.01			
				30	7.5	.10			
				4	.7	<.01			
4-9-62				20	2.3	.01			
				30	4.5	.03			
				8	.7	<.01			
5-7-62				20	2.1	.01			
				30	4.1	<.01			
				15.5	1.2	<.01			
6-18-62				20	17.0	.18			
				30	21.3	.24			
					--	--			

and k_1 generally observed at the 30°C incubation temperature, while the lower values were noted at the lower temperatures.

Mixing vs. Non-Mixing

The standard BOD procedure recommends running the test under quiescent conditions which are radically different from the normal conditions of turbulence prevailing in a natural stream. To more closely approximate the natural conditions, selected BOD rates were run under continuous mixing in sealed BOD bottles, with mixing supplied by means of magnetic stirrers.

Table 5-7 is a summary of the results for the Dow activated sludge effluent and the Smith's Crossing sampling station indicating the BOD_5 in mg/l and the k_1 obtained for the first five days of the rate study. More complete rate summary data is presented in Appendix II-B of this report.

TABLE 5-7

BOD RATE SUMMARIES, TITTABAWASSEE RIVER, 1961

Mixing vs. Non-Mixing
Standard Incubation Temperature - 20°C

Date	Dow (Effluent)			Smith's (Sta. 6,7,8)		
		BOD_5	k_1		BOD_5	k_1
5-4-1961	M	15.0	.07			
	NM	9.7	.14			
6-20-61				M	7.4	.05
				NM	3.1	.08
6-29-61				M	5.3	.07
				NM	3.7	.02
7-6	M	9.6	$<.01$	M	5.3	.07
	NM	6.2	$<.01$	NM	3.3	$<.01$
7-13-61	M	5.0	.06			
	NM	5.1	.07			

Inspection of the results presented in Table 5-7 indicates that in all cases but one, mixing caused a higher BOD_5 over that determined on the non-mixed sample. However, this was not the case for the k_1 values where it is seen that in only 50 per cent of the cases was the mixed value higher than the non-mixed value. It is apparent that the magnetic stirrers used for mixing purposes in the laboratory do not fully duplicate the natural conditions of turbulence found in the stream and, therefore, it is too much to expect that this laboratory apparatus will give k_r = 0.2 found in the Tittabawassee River.

Long Term Rates

As in the case of the Clinton River, selected samples of both the Dow waste treatment plant effluent and Tittabawassee River water were incubated for varying periods of time beyond the usual period of 7 to 14 days, extending in one instance to as long as 164 days.

Table 5-8 is a summary of the results for the selected samples, indicating among other things the k_1 obtained from the first five days of observation, together with a k_1 calculated from BOD_5 and BOD_{final}, assuming that the latter figure represents the ultimate BOD. Inasmuch as the BOD rates were conducted over varying periods of time, the k_1 values presented in the last column of Table 5-8 are not directly comparable but are presented as a matter of information. Also, the BOD figures presented in Table 5-8 represent total oxygen utilized, with no attempt made to distinguish between the carbonaceous and nitrogenous demands.

As a typical illustration, Figure 5-7 presents the short term (Curve A) and the long term (Curve B) BOD rate information for a Tittabawassee River sample collected at Smith's Crossing on August 24, 1961, during the intensive river survey. Inspection of Curve B shows that a second stage appears to start at the 30th day, with oxygen still being utilized after 90 days. Other Tittabawassee River samples followed a similar pattern, with two or three stages commonly present.

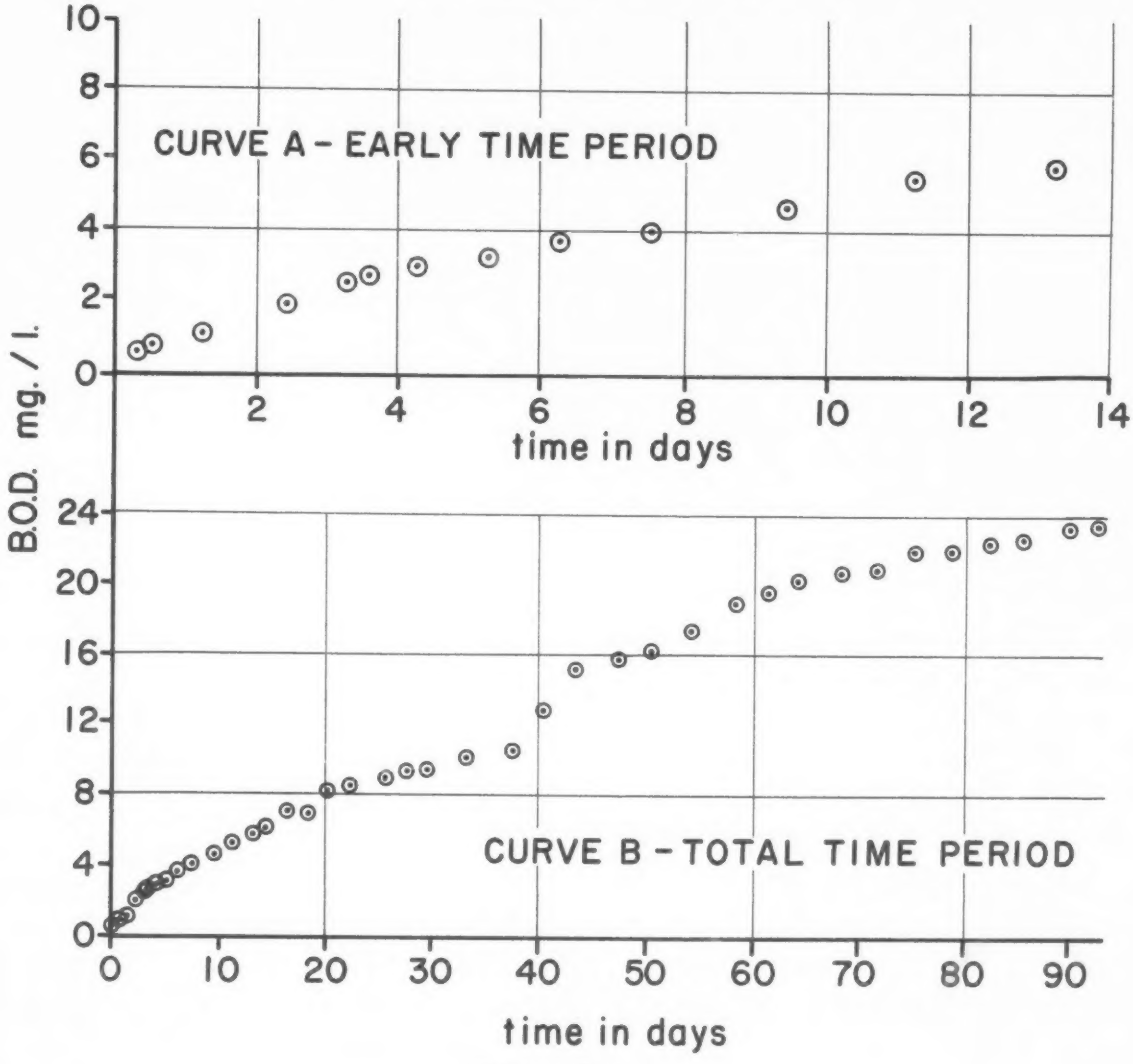
As in the case of the Clinton River samples the question might be raised--Is there an explanation for this? The same possibilities can be suggested here, namely, a readjustment of the internal microorganism population resulting in the breakdown of materials not previously broken down, or, the breakdown of the more complex compounds with time into simpler compounds, which then become available for biochemical oxidation.

TABLE 5-8

BOD RATE SUMMARIES, TITTABAWASSEE RIVER, LONG TERM RATES

Incubation Temperature, 20°C

Station	Date of Collection	Rate Duration Days	k_1 for First 5 Days	BOD_5 mg/l	BOD Final mg/l	BOD_5 as % of BOD Final	k_1 from BOD_5 and BOD Final
Currie St. Bridge	8-24-61	92.24	.02	1.77	9.58	18.5	.018
Benson St. Bridge	8-3-60	41.81	.07	4.43	10.25	43.2	.049
Dow Final Effluent	7-12-60	26.59	.05	4.75	15.91	29.9	.031
	8-3-60	28.61	< .01	5.41	13.15	41.1	.046
	8-24-61	52.47	< .01	3.65	33.67	10.8	.010
	3-5-62	30.59	.04	10.73	42.15	25.5	.026
	4-9-62	27.91	< .01	6.58	31.95	20.6	.020
	8-15-62	148.53	.05	2.26	91.52	2.5	.002
Smith's Crossing	8-3-60	25.84	.03	2.96	10.85	27.3	.028
	8-24-61	92.24	.07	3.12	23.43	13.3	.012
	8-15-62	164.29	.08	2.12	35.35	6.0	.005
Freeland Bridge	8-3-60	25.84	.09	3.15	11.50	27.4	.028
	8-24-61	107.23	< .01	2.56	22.71	11.3	.010



B.O.D. RATE

TITTABAWASSEE RIVER AT SMITH'S CROSSING

SAMPLE COLLECTED 8-24-61

Figure 5-7

SUMMARY AND CONCLUSIONS

Summaries of BOD rate studies conducted on samples of both Clinton River and Tittabawassee River waters during the period 1960-1962 have been presented. These summaries are broken down for each river into seasonal variation, temperature variation, mixing vs. non-mixing, and long term rates.

In the case of the Clinton River, the most noticeable differences appeared in the mixing vs. non-mixing category, with no conclusive variation demonstrated on a seasonal or temperature basis. Also, the long term rates indicated no complete stabilization in terms of oxygen demand, even in the case of the sample incubated for 166 days.

As far as the Tittabawassee River is concerned, it has not been possible to demonstrate BOD k_1 rate differences on either a seasonal, temperature, or mixing basis. Also, as with the long term Clinton River rates no complete stabilization in terms of oxygen demand was demonstrated even for the rate which was run for 164 days.

REFERENCES

1. Elmore, Harold L., "Determination of BOD by a Reaeration Technique," Sewage and Industrial Wastes, 27:9:993 (September, 1955).

SECTION VI

BOD PROCEDURES

One of the important analytical procedures in this research has been the BOD test used on both river water and treatment plant effluents. Much has been written on this subject in the past and a subsequent section of this report will present a review of the BOD literature. Insofar as possible, procedures suggested in Standard Methods(2) or developed by other investigators such as Elmore(1) were used, but as the study progressed, it became necessary to evaluate the influence of certain variables that had not been previously reported on by other writers.

This section of the report will consider the BOD reaeration procedure for rate studies which was the method most frequently used, including the results of replication tests conducted on both Clinton River and Tittabawassee River water. Also to be considered is a comparison of reaeration and dilution BOD results, a comparison of mixing and non-mixing BOD results, the influence of dilution on river BOD_5, BOD incubation under light and dark conditions, the influence of settling and filtering on BOD results, nitrification influence on BOD results, and the influence of effluent chlorination on BOD.

In addition, discussion is presented on the development of continuous BOD instrumentation using a galvanic cell oxygen electrode sealed in a respirometer cell. Finally, consideration is given to dissolved oxygen procedures, including a comparison among analysts using the Winkler method, a comparison of polarographic and Winkler D.O. results for both the Clinton River and Tittabawassee River water samples, and a discussion of applications of the galvanic cell oxygen analyzer.

BOD Reaeration Procedure

Major reliance in this project has been placed on the reaeration procedure for conducting BOD rate studies as proposed by Elmore.(1) Briefly, the technique consists of collecting a large volume of sample generally in the 3 to 5-gallon range, bringing it into the laboratory and aerating it with compressed air to bring the oxygen concentration close to saturation, filling a series of sealed

BOD bottles and then incubating these small bottles together with the larger remaining part of the sample. The dissolved oxygen in the sealed bottles is measured initially and at various selected time intervals. When the dissolved oxygen level in the sealed bottles approaches 2 mg/l, the large unsealed bottle is aerated and another set of sealed bottles is prepared as initially, with the process then repeated through any desired time interval. Further details of sample handling have been presented elsewhere by Elmore(1) and will not be repeated here. The successive oxygen depletions can be summed, resulting in the availability of a BOD vs. time relationship, with each point obtained from a dissolved oxygen determination on a single sealed bottle.

Some of the advantages of this procedure include the fact that the river water sample is used as it is collected without alteration. This more closely approaches the natural state without dilution, buffering, etc., which is the case where standard dilution water is used. Also, there is saving in initial setup time, together with a saving in time resulting from the fact that no seed, blanks, or dilution water is needed.

Counterbalancing these advantages, some of the disadvantages include the fact that the procedure is usually not recommended for samples having a BOD_5 greater than 25 mg/l because of the frequent need for reaeration. This, of course, is only a minor disadvantage in stream survey work because rarely do rivers have BOD_5 concentrations greater than this figure. Other disadvantages include the need for a larger sample volume together with the need for more incubator capacity. Also, more attention has to be given to the sample after the initial setup than would be needed in the case of the dilution procedure. Notwithstanding these minor disadvantages, it appeared the advantages greatly outweighed the disadvantages in terms of the objective of this project, and this procedure, therefore, became the one most commonly employed.

Careful attention has been given throughout the project to good laboratory procedure, with all laboratory assistants carefully trained and supervised. To evaluate the precision of the BOD reaeration procedure for Clinton River and Tittabawassee River water samples, special replication studies were conducted in June and July of 1962. In each case, 25 gallons of river water were collected and brought to the School of Public Health laboratories where they were placed in a single container and thoroughly mixed. From this single source, 5 separate 5-gallon containers were filled for replication studies.

The first 25-gallon sample was collected at Auburn Heights on the Clinton River on June 26, 1962, while the second 25-gallon sample was collected at Smith's Crossing on the Tittabawassee River on July 2, 1962.

Table 6-1 presents the results of the Clinton River study where it is seen that the standard deviation (σ) had a mean value of 0.22 mg/l for all the time periods, and a range of 0.03 mg/l to 0.45 mg/l. In addition, it is seen that the coefficient of variation tends to be fairly constant in the range of 2 to 3 per cent except in the early time periods.

Table 6-2 presents the results of the Tittabawassee River study where it is seen that the standard deviation (σ) had a mean value of 0.19 mg/l for all the time periods, and a range of 0.10 to 0.29 mg/l. Here the coefficient of variation tends to be higher in the range of 3 to 8 per cent, except for the early time periods, in contrast to the Clinton River range of 2 to 3 per cent. This is primarily due to the fact that the Tittabawassee River BOD figures are lower than those for the Clinton River for the same time period, while the standard deviation figures are approximately the same. This indicates, therefore, that the precision of the procedure as indicated by the standard deviation is not a function of BOD level, at least not in the ranges encountered in this experiment, but rather, appear to be associated with some constant experimental error involving the mechanics of the procedure itself. These results are in excellent agreement with the results of a similar experiment presented by Elmore,(1) suggesting that the procedures employed by both this group and Elmore are the same.

As an additional check during the months of May, June, and July, 1961 each observation was made in duplicate in the routine reaeration procedure. Generally these duplicate results were well within the range of variation indicated in Tables 6-1 and 6-2, and as a result of this excellent agreement, it was decided at this

TABLE 6-1

PRECISION OF BOD REAERATION PROCEDURE

Clinton River at Auburn Heights
Sample Collected June 26, 1962

Time in Days	BOD mg/1					Avg BOD mg/1	Std Deviation mg/1	Coefficient of Variation
	A	B	C	D	E	$\overline{X}$	σ	%
0.271	0.25	0.30	0.25	0.30	0.30	0.28	0.03	10.71
0.729	1.00	1.05	1.00	1.15	1.15	1.07	0.08	7.48
1.000	1.15	1.15	1.15	1.25	1.25	1.19	0.05	4.20
1.219	1.35	1.40	1.35	1.35	1.40	1.37	0.03	2.19
1.729	2.05	2.00	2.00	2.10	2.60	2.15	0.25	11.62
2.042	2.10	2.30	2.40	2.30	2.35	2.29	0.11	4.80
2.729	3.15	3.20	3.20	3.20	3.30	3.21	0.05	1.56
3.042*	3.55	3.70	3.70	3.65	3.65	3.65	0.06	1.64
3.740	4.35	4.50	4.50	4.60	4.40	4.47	0.10	2.24
4.896	6.35	6.45	6.55	6.90	6.40	6.53	0.22	3.37
5.750*	8.70	9.00	9.25	9.45	9.05	9.09	0.28	3.08
6.729	10.70	11.10	11.00	11.85	10.85	11.10	0.45	4.05
7.000*	11.90	11.70	11.60	12.05	11.35	11.72	0.27	2.30
7.813	13.80	13.45	13.30	13.85	13.25	13.53	0.28	2.06
8.719	15.55	15.20	15.10	15.65	14.95	15.29	0.30	1.96
9.021*	16.00	15.85	15.45	16.15	15.40	15.77	0.33	2.09
9.729	16.60	16.45	16.00	16.75	15.90	16.34	0.37	2.26
10.750	17.10	16.90	16.50	17.35	16.60	16.89	0.35	2.07
11.792	17.65	17.20	16.85	17.70	16.90	17.26	0.40	2.32
12.750	17.90	17.80	17.25	18.05	17.20	17.64	0.39	2.21

Mean Standard Deviation	Range of Std. Dev.	Mean Coef. Variation	Range of Coef. Variation	
0.22	0.03 ⟶ 0.45	3.71	1.56 ⟶ 11.62	

*Samples reaerated.

TABLE 6-2

PRECISION OF BOD REAERATION PROCEDURE

Tittabawassee River at Smith's Crossing

Sample collected July 2, 1962

Time in Days	BOD mg/l					Avg BOD mg/l	Std Deviation mg/l	Coefficient of Variation
	A	B	C	D	E	$\bar{X}$	σ	%
0.667	0.60	0.50	0.55	0.40	0.35	0.48	0.10	20.83
0.938	0.80	0.70	0.80	0.50	0.55	0.67	0.14	20.90
1.146	0.85	0.75	0.85	0.55	0.60	0.72	0.14	19.44
1.750	1.30	1.15	1.30	1.00	1.10	1.17	0.13	11.11
2.656	1.90	1.80	1.85	1.60	1.60	1.75	0.14	8.00
2.958	2.00	2.05	2.10	1.90	1.80	1.97	0.12	6.09
3.667	2.50	2.45	2.50	2.30	2.25	2.40	0.12	5.00
3.958	2.80	2.85	2.80	2.50	2.50	2.69	0.17	6.31
4.688	3.25	3.10	3.30	2.90	3.10	3.13	0.16	5.11
5.729	4.00	4.15	3.80	3.50	3.50	3.79	0.29	7.65
6.688*	4.40	4.20	4.40	4.05	3.95	4.20	0.20	4.76
6.958	4.45	4.30	4.65	4.25	4.15	4.36	0.19	4.36
7.688	4.80	4.45	4.90	4.50	4.35	4.60	0.24	5.22
8.667	4.95	4.80	5.20	4.75	4.55	4.85	0.24	4.95
9.667	5.25	5.05	5.60	5.15	4.95	5.20	0.25	4.81
10.667	5.55	5.35	5.85	5.45	5.15	5.47	0.26	4.75
11.677	5.80	5.65	6.05	5.65	5.45	5.72	0.22	3.85
12.771	6.30	5.90	6.50	5.95	5.95	6.12	0.27	4.41
13.667	6.40	6.45	6.70	6.45	6.15	6.43	0.20	3.11

Mean Standard Deviation	Range of Std. Dev.	Mean Coef. Variation	Range of Coef. Variation	
0.19	0.10 → 0.29	7.93	3.11 → 20.90	

*Samples reaerated.

time to make one D.O. determination at each observation period rather than two, as had been previously done.

Comparison of Reaeration and Dilution BOD Results

To evaluate the influence of using either the reaeration or dilution BOD procedure, selected samples of both the Clinton River and Tittabawassee River were analyzed using both procedures run in parallel. The dilution method followed is that recommended in the 11th Edition of Standard Methods,(2) while the reaeration procedure was described in the preceding section of this report. As a control on the dilution method, the glucose-glutamic acid check as suggested in Standard Methods(2) was run periodically throughout the study, especially when new laboratory assistants joined the project. This served not only as a check on the laboratory technique of the analyst, but also, tested the adequacy of the dilution water. Using standard sewage seed from the Ann Arbor plant, these results were within the ranges reported in Standard Methods(2) and, also, those reported by Sawyer et al.(3) and more recently by Ballinger and Lishka.(4)

Of the samples run on the Clinton River water and the Pontiac effluent, no consistent pattern developed between the results of the reaeration and dilution procedures. In some cases the dilution technique developed the higher BOD results, while in others the reaeration procedure gave higher results. Generally, however, the results were close to each other suggesting a minimal influence on the part of the procedure used. Also, the k_1 rates were usually less than .01 regardless of the procedure followed.

On the other hand, in case of the Tittabawassee River water and Dow effluent samples, the dilution method gave consistently higher results over the reaeration procedure. Also, where two dilutions were run at the same time, the higher dilution gave the higher results. For example, a 25 per cent dilution water, 75 per cent river water sample gave a result higher than a 100 per cent river water sample run for the same time period, and a 50 per cent dilution water and 50 per cent river water sample, gave a result higher than a 25 per cent dilution water, 75 per cent river water sample, also run at the same time period.

B.O.D. RATE
REAERATION VS. DILUTION PROCEDURE

TITTABAWASSEE RIVER AT SMITH'S CROSSING
SAMPLE COLLECTED 7-23-62

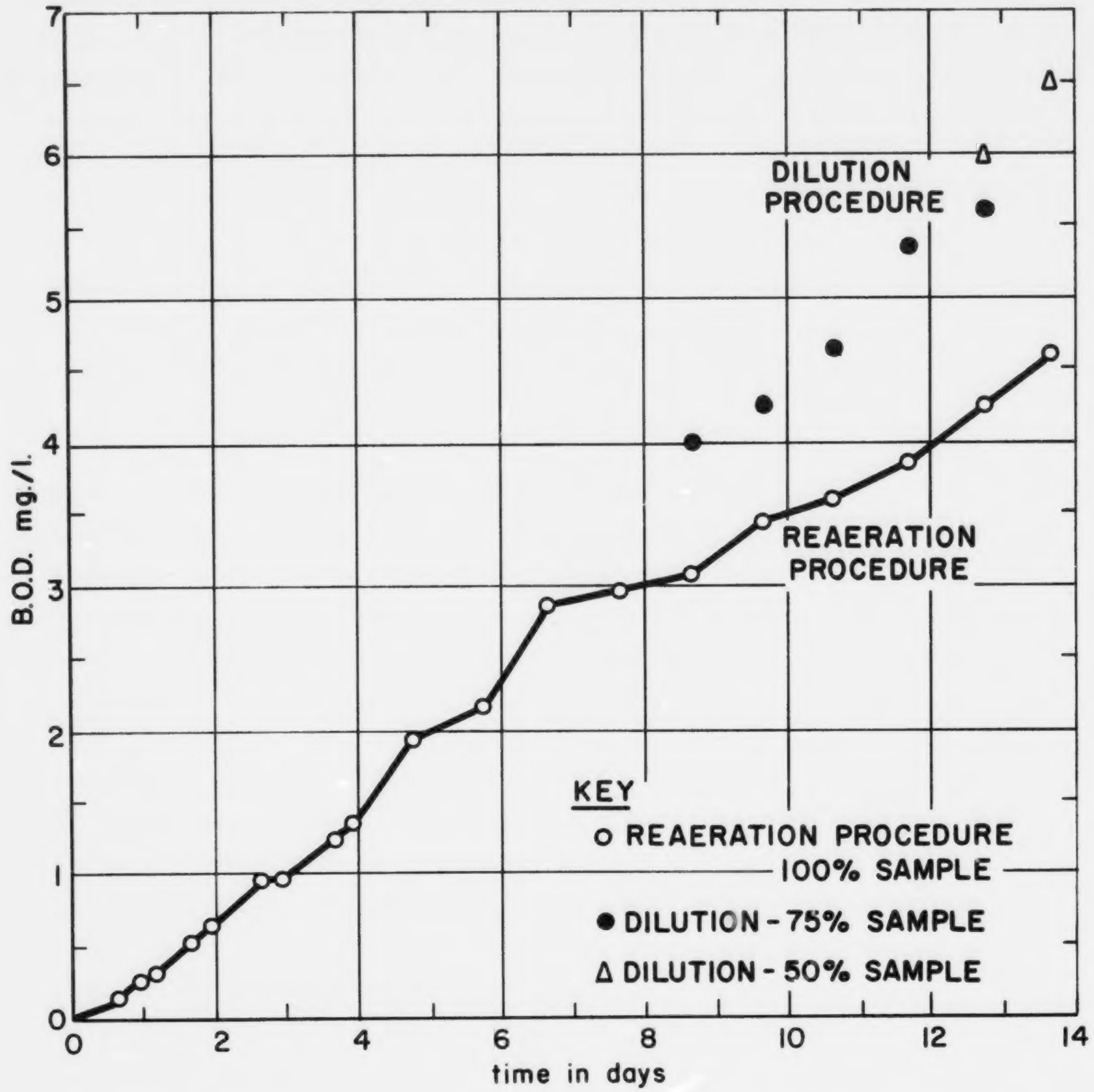


Figure 6-1

These points are illustrated more specifically in terms of an illustration presented in Figure 6-1. Here, the results of the reaeration and dilution procedures are shown for a sample of Tittabawassee River water collected at Smith's Crossing bridge on July 23, 1962. It is seen, for example, that until 8.65 days, the reaeration results and the 100 per cent dilution results are one and the same since no dilution was involved in either case. At this time, however, when the first dilution is reported it is seen that the 100 per cent river water, and 75 per cent river water 25 per cent dilution water are different, with the latter dilution giving the higher results. For all subsequent readings, the dilution samples gave the higher results, where it is also seen that at 12.75 days the 50 per cent river water sample gave results higher than the 75 per cent river water sample. Inasmuch as most of the Tittabawassee River samples had low BOD values, it generally was not necessary to dilute the samples for the first 5 days of the rate, and, as a result, the k_1 value was the same within the first 5 days regardless of the procedure used. The influence of dilution on the standard BOD_5 result will be discussed in a subsequent part of this report.

Comparison of Mixing and Non-Mixing BOD Results

To more closely approach the natural conditions of turbulence found in a stream, a series of rates were run on selected samples under continuous mixing using magnetic stirrers. Several shaking and mixing devices were investigated before it was decided to use the magnetic stirrers arranged in a walk-in incubator held at $20^{\circ}C$ as shown in Figure 6-2. It is to be noted that sealed BOD bottles were placed on individual magnetic stirrers, with the speed of rotation synchronized by means of a stroboscope mounted in the upper left part of the picture. In addition, the influence of line voltage fluctuations on the speed of rotation was minimized by the use of powerstats as illustrated. Asbestos pads were used to control the transference of heat from the magnetic stirrer to the BOD bottle, and it was possible by means of this technique to maintain the bottles at $20^{\circ}C$.

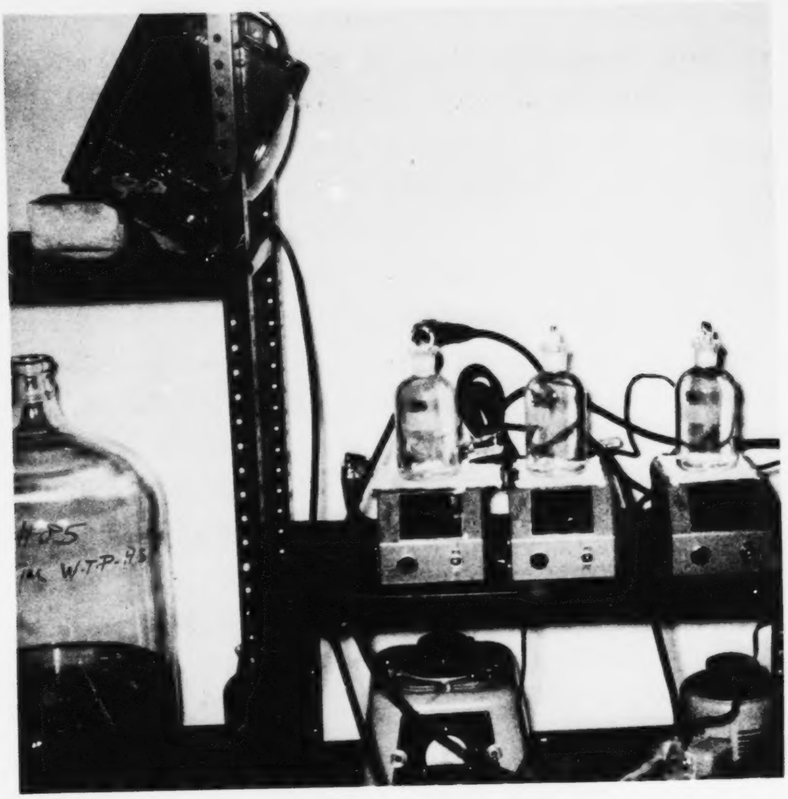


Figure 6-2. Photograph of mixing equipment.

The procedure followed was in effect a modification of the standard reaeration technique, where the individual sealed BOD bottles and the larger open jug were maintained under constant mixing by means of magnetic stirrers. When all the sealed BOD bottles were utilized, the large jug was reaerated and another series of sealed BOD bottles set up on the stirrers. Thus, the procedure was the same as the standard reaeration method except for the mixing.

In the case of the Clinton River samples, mixing consistently caused an increase both in BOD level and k_1 rate over those observed in the quiescent samples. It should be noted that the Clinton River water had more settleable material present in it than the Tittabawassee River water, and where settleable material is present it is expected that mixing would exert the greatest influence by keeping this material in suspension. Figure 6-3 presents the results of a typical mixing versus non-mixing experiment conducted on a sample of Clinton River water collected at Auburn Heights on June 22, 1961. As previously indicated, the mixing BOD level and k_1 rate is higher than the non-mixed sample.

Because the Tittabawassee River water and the Dow effluent had fewer settleable solids present than the Clinton River and the Pontiac activated sludge effluent, the influence of mixing on the BOD results was less pronounced. However, as indicated in the preceding section of this report, the mixing BOD level was consistently higher than the non-mixed level although the k_1 rate was not. If additional mixing rate studies had been conducted on Tittabawassee River water, it is the feeling of the writer that the results would closely parallel those of the Clinton River investigations.

It is interesting that Lordi and Heukelekian(5) presented a paper on the effect of rate of mixing on deoxygenation of polluted waters at the 16th Purdue Industrial Wastes Conference in May, 1961 and concluded that the deoxygenation rate was definitely increased with mixing. Their experimental apparatus was different from that used in this investigation, and involved an open vessel which then necessitated a calculated correction for the influence of reaeration.

B.O.D. RATE
MIXED VS. NON-MIXED
CLINTON RIVER AT AUBURN HEIGHTS
SAMPLE COLLECTED 6-22-61

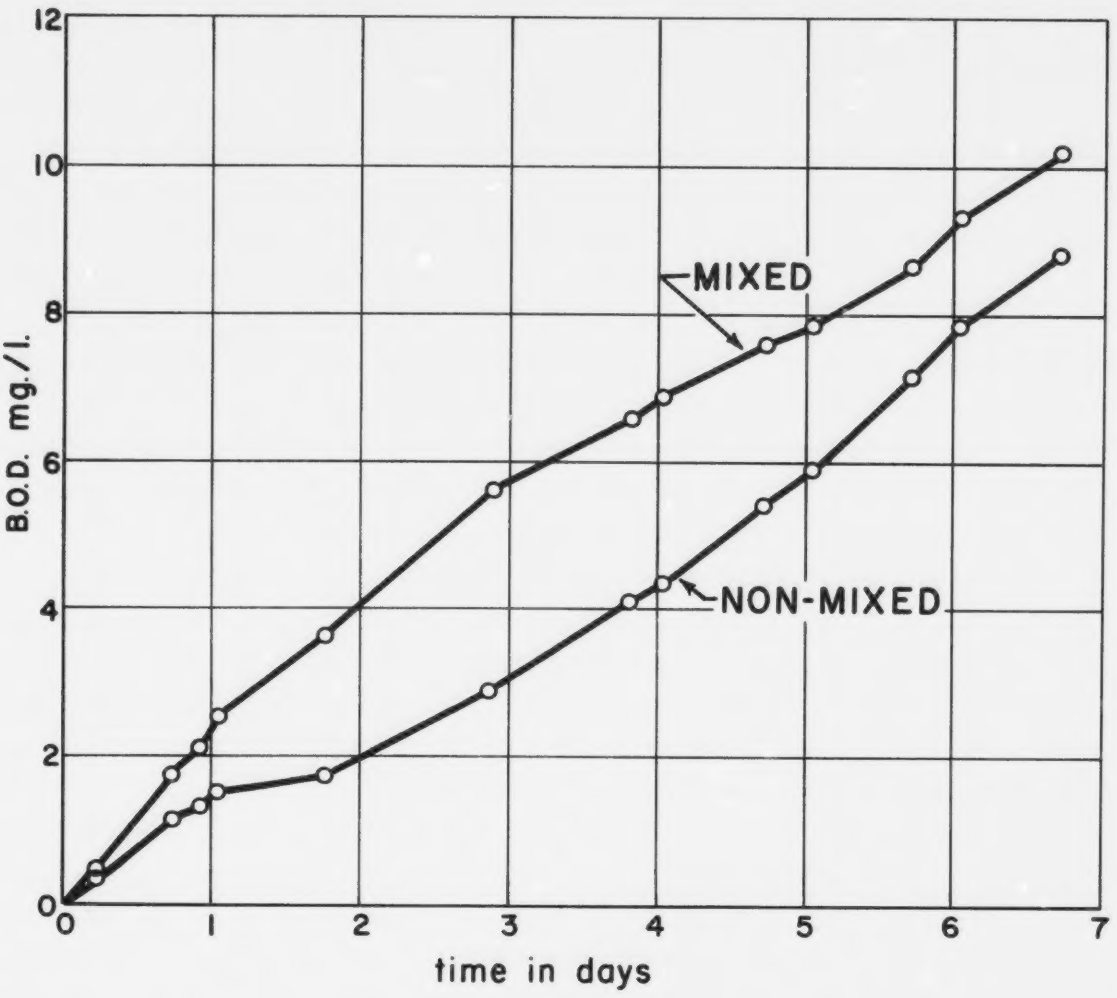


Figure 6-3

Dilution Influence on River BOD_5

During the course of analysis of the August, 1961 intensive river water quality data on the Tittabawassee River survey, it became apparent that dilution had a significant influence on the routine river BOD_5 results, particularly in the usual dilution ranges of 100%, 50%, 25%, etc. of river water. This is demonstrated by a comparison of the 50% and 100% dilution results for the samples collected at the three regular sampling stations at Smith's Crossing bridge, during the survey period August 23-25, 1961. At this sampling station, therefore, each routine BOD_5 was run at both 100% river water, and 50% river water and 50% standard dilution water, with the 50% river water sample giving consistently higher values.

The results of both the 100% dilution and the 50% dilution samples are summarized by means of normal probability paper as illustrated in Figure 6-4. The use of normal probability paper in summarizing data has been presented elsewhere in more detail by Gannon(6) and Velz.(7) Looking at Figure 6-4, it is seen that both sets of observations describe a reasonably straight line, suggesting that the normal distribution expresses the variation of the data. From these plots, the following summary information is obtained:

50% BOD Dilution	100% BOD Dilution
$\bar{X}$ = 5.48 mg/l	$\bar{X}$ = 3.7 mg/l
σ = 1.18 mg/l	σ = 1.07 mg/l
n = 36 observations	n = 36 observations
$SE = \frac{\sigma}{\sqrt{n}} = \frac{1.18}{\sqrt{36}} = 0.20$ mg/l	$SE = \frac{1.07}{\sqrt{36}} = 0.18$ mg/l

Obviously a difference exists between the mean values of 5.48 mg/l and 3.7 mg/l, but is this difference significant or could it be due to chance? This question can be resolved by the simple overlapping test for statistical significance as previously described by Gannon.(6) Using the 95% confidence level, it is seen that the mean 50% BOD dilution result of 5.48 mg/l had a lower limit of $5.48 - 2(0.2) = 5.08$ mg/l, while the mean 100% BOD dilution

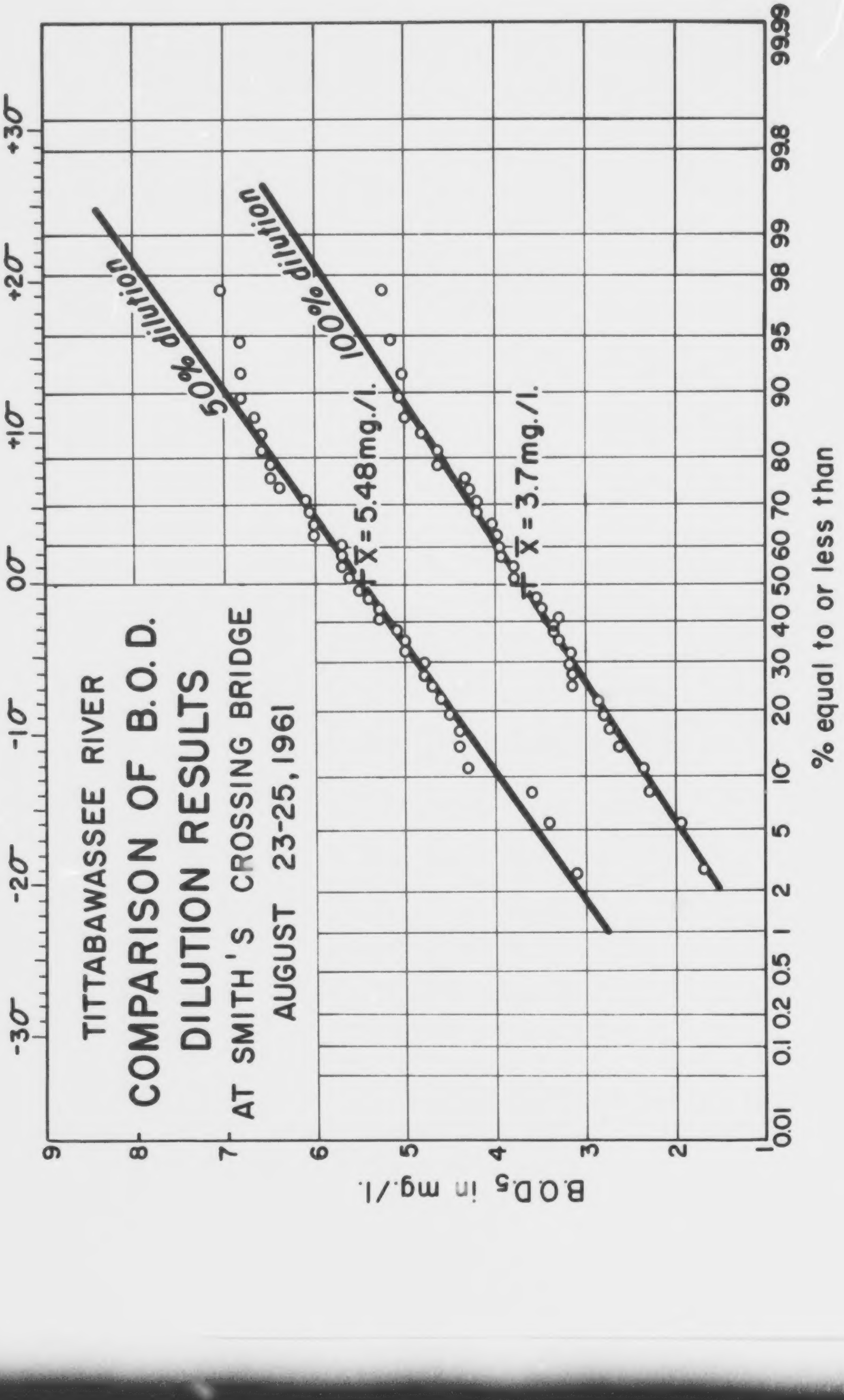

TITTABAWASSEE RIVER
COMPARISON OF B.O.D.
DILUTION RESULTS
AT SMITH'S CROSSING BRIDGE
AUGUST 23-25, 1961
50% dilution
100% dilution
X̄ = 5.48 mg./l.
X̄ = 3.7 mg./l.
-3σ
-2σ
-1σ
0σ
+1σ
+2σ
+3σ
B.O.D.5 in mg./l.
1
2
3
4
5
6
7
8
9
% equal to or less than
0.01
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.99

Figure 6-4

of 3.7 mg/l had a higher limit of $3.70 + 2(.18) = 4.06$ mg/l, indicating a definite difference. The conclusion can be drawn, therefore, that there is a statistically significant difference at the 95% confidence level between the mean values of the 50% and 100% BOD dilution results.

Fortunately, during the 1961 survey, a 50% BOD dilution was run on all samples collected in the lower river. Efforts were directed toward establishing relationships between various dilutions, using correlation techniques, so that 100% BOD dilution results could be predicted where they were not run, but this approach did not prove profitable. As a result, the decision was made to use only the observed 50% BOD dilution results in the river analysis work previously described in this report for the sake of uniformity.

In the case of the Clinton River 1960 intensive survey routine BOD_5 results, the influence of dilution on the BOD_5 measurement was not as pronounced as in the case of the Tittabawassee River data, and it was not possible to separate the various dilutions.

BOD Incubation under Light and Dark Conditions

The standard BOD procedure calls for the incubation of samples under quiescent conditions, generally in a darkened incubator. This, of course, is drastically different from the natural conditions of turbulence, and alternating light and dark conditions found in the river or stream. The influence of mixing has been previously discussed, while it is the intent here to describe experiments conducted to evaluate the influence of BOD incubation under continuous light, and, also, under conditions of alternate light and dark periods, corresponding to natural day and night cycles.

For purposes of conducting this experiment, two BOD incubators were outfitted with cool, white fluorescent lights which could be left on continuously, or which could be set to approximate natural day and night periods by means of a timer mechanism. Light meter readings in the incubator ranged from 180 foot-candles in the middle of the floor, to 600 foot-candles at a distance 2 inches from the light. In contrast, natural light intensities ranged from a low of 200 foot-candles at dusk to over 3000 foot-candles in the bright sun. Thus, the incubator light intensity was considerably less than that found under natural conditions.

Selected samples of both the Clinton River and the Tittabawassee River water collected in the summer of 1961 were incubated under experimental conditions of continuous light and, also, alternate periods of light and dark. Those samples incubated under continuous light started producing oxygen almost from the beginning of the incubation period and, thus, showed a net gain on oxygen, rather than a demand as indicated in parallel samples incubated in the dark. Those samples incubated under alternating light and dark conditions showed a demand up until 4 or 5 days, and then started producing oxygen. Because of these variations, no attempt was made to obtain a meaningful k_1 value for this data.

It is obvious that oxygen is being produced as a result of photosynthetic activity by algae in the river water samples. Microscopic evaluation confirmed the presence of algae, and, also, the diurnal fluctuation in river D.O. during the intensive river surveys on both rivers supported this finding. It is interesting that Varma, Horn, and Reid(8) recently reported on experiments which paralleled the experiments and findings of this study. They suggested the light-dark incubation method, if properly used, would give more representative BOD values than the standard dark incubation method.

Others, notably Wisniewski(9) and Bartsch,(10) have raised questions as to the role of algae in river BOD determinations. If a river water sample is incubated in the dark, the algae may die and, no doubt, add to the total BOD, making it difficult to evaluate the relative contribution of the organic matter and the algae. Thus, samples involving algae, when incubated in the dark, may show a higher BOD than is actually present. The findings of this study, together with the findings of others, suggest the investigation of the role of algae in river BOD determinations as an area of fruitful research. No further work has been done on this project, beyond the limited rate studies run under light and dark conditions during the summer of 1961.

Influence of Settling and Filtering on BOD Results

Special studies were conducted in July of 1962 to evaluate the influence of settling and filtering samples in terms of both BOD level, and k_1 rate, using the reaeration procedure. Settling was accomplished by bringing the sample into the laboratory, allowing it to stand for 1 hour, and then siphoning off the supernatant liquid for rate analysis. Filtering was accomplished by passing the sample through a coarse filter paper.

The results for samples collected on July 17, 1962 of the Clinton River at Auburn Heights and the Pontiac activated sludge effluent are presented in Table 6-3. It is seen that for the Auburn Heights sample the BOD level is slightly higher for the regular non-settled sample, but the k_1 rate is higher for the filtered sample. On the other hand, in the case of the Pontiac effluent, it is seen that the BOD level for the regular non-settled sample is substantially above the settled and filtered samples. Moreover, as with the Auburn Heights sample, the filtered k_1 value is higher than the other two. These results suggest that the Pontiac activated sludge effluent had a higher BOD in the solids form, which was removed in about the same degree by settling and filtering. No explanation is available as to why the filtered k_1 value was higher in both cases.

TABLE 6-3

COMPARISON OF NON-SETTLED, SETTLED, AND FILTERED RESULTS USING REAERATION PROCEDURE

Clinton River at Auburn Heights
Sample Collected July 17, 1962

	BOD_5 mg/l	BOD_{10} mg/l	BOD Final mg/l	Rate Duration in Days	k_1 Rate
Non-settled (Regular Rate)	2.56	12.00	28.00	19.698	$<.01$
Settled	1.98	10.90	19.45	13.698	$<.01$
Filtered	2.08	10.99	21.00	13.698	.03

TABLE 6-3 (cont'd)

Pontiac Activated Sludge Effluent

Sample Collected July 17, 1962

	BOD_5 mg/l	BOD_{10} mg/l	BOD Final mg/l	Rate Duration in Days	k_1 Rate
Non-settled (Regular Rate)	5.20	28.69	59.00	19.70	$<.01$
Settled	1.28	6.57	21.80	13.70	$<.01$
Filtered	1.26	1.73	2.45	13.70	.09

The results for the samples collected on July 23, 1962 of the Tittabawassee River at Smith's Crossing and the Dow waste treatment plant effluent are presented in Table 6-4. In both illustrations, it is seen that the BOD level of each method of handling, i.e., non-settled, settled, or filtered, is about the same, indicating very little BOD in the solids form. Also, the k_1 values are consistently low, in the order of magnitude of less than 0.01, with the exception of the settled Smith's Crossing sample.

These experiments tend to confirm the assumption that most of the BOD is in the colloidal and dissolved form, rather than the settleable form, with the possible exception of the Pontiac activated sludge effluent. Both river water samples showed little difference among the three methods of handling.

TABLE 6-4

COMPARISON OF NON-SETTLED, SETTLED, AND FILTERED RESULTS USING REAERATION PROCEDURE

Tittabawassee River at Smith's Crossing

Sample Collected July 23, 1962

	BOD_5 mg/l	BOD_{10} mg/l	BOD Final mg/l	Rate Duration in Days	k_1 Rate
Non-settled (Regular Rate)	2.00	3.50	4.60	13.677	$<.01$
Settled	2.05	3.97	5.25	13.677	.04
Filtered	2.30	4.13	4.85	13.677	$<.01$

TABLE 6-4 (cont'd)

Dow Waste Treatment Plant Effluent

Sample Collected July 23, 1962

	BOD_5 mg/l	BOD_{10} mg/l	BOD Final mg/l	Rate Duration in Days	k_1 Rate
Non-settled (Regular Rate)	2.67	4.42	5.55	13.677	<.01
Settled	2.20	3.53	4.15	13.677	<.01
Filtered	2.16	3.45	4.15	13.677	<.01

Nitrification Influence on BOD Results

As an aid in interpretation of BOD rate information, it was decided early in 1961 to attempt to evaluate the degree of nitrification occurring during the course of routine rate studies. This information, then, would supplement the usual oxygen determinations made as part of the reaeration procedure. It is generally accepted that nitrogen utilizes oxygen in going from NH_3 to NO_2 to NO_3, the latter being the more stable form from an oxygen consuming standpoint. Uncertainty exists in the field as to when nitrification starts in the BOD reaction, and its relative influence.

To evaluate the degree of nitrification involved, it was decided to measure the concentration of NH_3, NO_2, and NO_3 at the beginning, the mid-point, and end of every routine BOD rate study that was run for the usual duration of 7 to 14 days. Ideally, of course, it would be desirable to make these determinations every time an oxygen measurement was made, but this proved impractical because of the time involved. Usually it took a competent laboratory analyst about three hours to run the three nitrogen tests on aliquots of the rate samples. Each determination was made in accordance with the procedures established in the 11th Edition of Standard Methods,(2) with nitrogen ammonia run by the direct nesslerization method, and nitrogen nitrate run by the phenoldisulfonic acid method. Inasmuch as chloride concentration is needed for the nitrate determination, it became necessary to run this test as part of the nitrogen tests using the potentiometric method. These determinations were routinely run on all rates starting in April, 1961 and continuing through the completion of the rate studies in August, 1962.

As has been brought out in earlier sections of this report, nitrification has been a definite influence on the BOD rate studies conducted on the Clinton River samples, but not on the Tittabawassee River samples. The routine nitrogen determinations on the Clinton River samples have been a big help in interpreting the BOD information. As discussed in the Clinton River section, active nitrification usually starts before 5 days of incubation in the laboratory in the case of the Adams Road samples, and in about 50% of the Auburn Heights samples. However, it has been brought out that nitrification does not occur in the river, at least not to the low point in the oxygen sag at Auburn Heights. Thus, nitrification is a definite problem in terms of the laboratory procedure, but not in terms of the critical river oxygen levels.

Toward the end of the field phase of this study in August, 1962 an attempt was made to study more intensively the nitrification progression on selected Clinton River samples, including an evaluation of the usual nitrification inhibition techniques using methylene blue, pasteurization, and acidification. It is beyond the scope of this report to consider fully all of the ramifications of nitrification, or to report on all of the nitrification findings of this investigation. Studies are currently underway to explore further the basic mechanisms involved, together with a more critical evaluation of nitrification inhibition techniques.

Others have reported on the influence of nitrification on river oxygen balances and on the BOD test, including the work of Courchaine(11) in relation to nitrification in the Grand River below Lansing, Michigan; the work of Wheatland,(12) et al. in Great Britain; the work of Ruchhoft(13) et al. on correction of BOD velocity constants for nitrification; the work of Sawyer and Bradney(14) giving procedures for the inhibition of nitrification by pasteurization and chlorination; the work of Huriwitz et al.(15) describing the use of acidification for inhibiting nitrifying organisms; and more recently the work of Symons(16) describing a procedure for continuous nitrification corrections during Warburg respirometer studies.

Influence of Effluent Chlorination on BOD

As has been reported earlier, chlorination of the Pontiac waste treatment plant effluent caused a chlorine residual to persist in the Clinton River as far downstream as the Grand Trunk railroad bridge during low flow periods. BOD rates were run on selected Pontiac trickling filter and activated sludge effluents after chlorination, with each sample split into two parts--one part was dechlorinated with sodium sulfite as recommended in Standard Methods,(2) while the other part was run as collected with a chlorine residual. The dechlorinated part behaved much as other effluent samples which were collected at a point in the plant before chlorination, while the chlorinated part showed no oxygen utilization for the first 3 or 4 days of incubation, but then became active at a rate equivalent to the dechlorinated sample. While no chlorine residual determinations were made on the incubated chlorinated sample, it can be assumed that no oxygen utilization occurred while a chlorine residual was present, but after the chlorine was utilized, oxidation again resumed at a normal rate. Thus, it can be assumed that chlorine might have functioned as a retarding and oxidizing agent, rather than as a sterilizing agent.

Others have reported on more comprehensive investigations in terms of the influence of chlorination on BOD, including the work of Baity and Bell(17) on BOD reduction by chlorination, where they concluded among other things that such BOD reductions are permanent; the work of Baity, Merrifield, and Uzzle(18) discussing some effects of sewage chlorination upon the receiving stream; the work of Groff and Ridenour(19) discussing the effect of breakpoint chlorination on sewage BOD; and more recently the work of Snow(20) on the BOD of chlorinated sewage.

Development of Continuous BOD Instrumentation

As the study progressed, it became apparent that the reaeration procedure used in conjunction with the usual wet chemical methods of dissolved oxygen determination involved considerable expenditure of effort, especially in the early stages of the rate when as many points as possible are desirable. Usually this meant a laboratory attendant on duty both day and night during the first two days of a rate study, and as a result, the availability of manpower became a limiting consideration as to the number of rates which could be run at a given time.

It became apparent that some type of continuous, automatic, or at least semi-automatic, BOD instrumentation could be used to advantage, both in terms of more frequent data during the early time periods, and, also, in terms of reduced manpower requirements. Two investigators recently proposed instrumentation for this purpose--the first was reported by J.W. Clark(21)(22)(23) of New Mexico State University who described a sealed digestor assembly, involving a procedure for producing oxygen by electrolysis and measuring the amount of this oxygen added to the assembly to replace oxygen utilized in the substrate. Thus, the amount of oxygen added is totaled with time and, in effect, becomes the BOD. The second proposed system was reported by Eye(24) et al. of the University of Cincinnati involving a sealed Erlenmeyer flask containing a platinum electrode system for oxygen measurements. All of the illustrations reported by Eye involved BOD_5 levels of 7.0 mg/l or less, which means that the oxygen initially present in the sample was adequate to meet the BOD_5 demand.

After careful evaluation of these two systems, it was decided neither method fully met the requirements of this project. As a result, it was decided during the spring and summer of 1962 to attempt to develop a more suitable apparatus. The Eye concept of including an oxygen electrode in a sealed reaction flask was appealing, but there needed to be some method of reaerating the sample if the oxygen level fell below 2 mg/l. Several oxygen electrode systems were investigated and it was finally decided that the galvanic cell type as proposed by Mancy, Westgarth, and Okun,(25) and by Mancy and Westgarth(26) had advantages for this purpose over several other types of oxygen electrodes currently in use.

A device was finally developed involving a galvanic cell oxygen electrode included in a sealed respirometer cell or reaction flask. The reaction flask selected was a standard 2-liter flask, with a specially constructed galvanic cell electrode, tapered to fit through one of the standard port openings. Ports are also available to permit aeration of the contents of the flask when the D.O. level drops to 2 mg/l. Further, the galvanic cell electrode can be connected to a standard strip chart recorder to permit continuous recording of residual oxygen concentration with time.

In operation, the procedure is a modification of the standard reaeration technique previously described, i.e., the sample is aerated and placed in the sealed respirometer cell with the galvanic cell oxygen electrode. The whole assembly is then placed in a standard BOD incubator on a magnetic stirrer to provide the necessary velocity for electrode response, with the oxygen electrode connected to a continuous recorder. When the oxygen concentration in the flask drops to 2 mg/l, the flask is aerated by means of compressed air and the whole procedure is then repeated as long as it is desired to keep the rate running. Obviously this procedure has the same advantages as the reaeration technique in that no dilution is involved but, also, has the added advantage of keeping the original sample intact, rather than splitting it up into several sealed BOD bottles.

Since the initial work in the summer of 1962, the apparatus has been under development and should be fully operational in the near future. Such things have been investigated as the BOD demand of parts of the electrode, the durability of the electrode under continuous use, the reproducibility of the procedure, the comparison of results using this method with other standard methods, together with several other factors. It is beyond the scope of this report to consider further the continuous BOD apparatus which will be reported on fully at a later date.

Dissolved Oxygen Procedures

Primary reliance for dissolved oxygen determination in this project has been on the Alsterberg (azide) modification of the Winkler method as outlined in the 11th Edition of Standard Methods.(2) Careful attention has been given to all of the recommended procedures including periodic standardization of the sodium thiosulfate solution. As a training exercise prior to the August, 1961 intensive river survey on the Tittabawassee River, a comparison was made among analysts with good chemistry backgrounds by having each analyst run independent duplicate dissolved oxygen determinations on samples taken from the same source. The results of this experiment are presented in Table 6-5 as follows:

TABLE 6-5

COMPARISON AMONG ANALYSTS FOR DISSOLVED OXYGEN DETERMINATIONS

Using Winkler Method (Azide)
August 15, 1961

Analyst	D.O. in mg/l	
	Run 1	Run 2
A	7.8	7.9
B	7.95	8.0
C	7.95	7.95
D	8.0	8.0
E	8.08	8.09

It is apparent from these results that the maximum difference was 0.29 mg/l between analyst A and E; however, if analyst A is not included the maximum difference was 0.14 mg/l. The one phase of the test most subject to individual interpretation is the starch-iodine end point, and it is this part of the test that made the greatest contribution to variation among analysts. It should be reported that analyst A did not run any sodium thisulfate titrations in D.O. analysis during the Tittabawassee River survey in August, 1961. Further training improved agreement among the other analysts.

Where dissolved oxygen samples were collected in the field, it was usual practice to add the $MnSO_4$ solution, the alkali-iodide-azide reagent, and the H_2SO_4 immediately after collection, reserving the sodium thiosulfate titration until the sample was returned to the laboratory.

As the study progressed, efforts were directed toward the development and use of oxygen determination methods that would save time, and thereby increase the productivity of the project staff. Equipment was available for the polarographic determination of dissolved oxygen using a dropping mercury-calomel electrode combination which was calibrated as outlined in Standard Methods.(2) Figure 6-5 shows the dropping mercury electrode assembly which was used in conjunction with a Model 65 Fisher elecdropode for voltage application and current measurement. The procedure for use of this method is outlined in Standard Methods(2) and will not be repeated here.

One of the advantages of this approach over the Winkler procedure is the speed of determination, especially in the laboratory where several dissolved oxygen determinations are to be made in succession. It has been estimated that under these conditions the normal laboratory time would be one to two minutes per determination. The equipment as available to this project was not adaptable for field use and was limited to the laboratory; however, it has recently been reported that field assemblies using this same principle are now commercially available. This method also has advantage over the Winkler method where certain interfering substances may be present. Because of these advantages, all laboratory dissolved oxygen determinations were made using this method during the spring and summer of 1962.

For purposes of comparison, a series of observations were made using both methods on Clinton River and Tittabawassee River water samples involving 10 replications by each method at each D.O. level. The results are presented in Tables 6-6 and 6-7 as follows, where it is seen that excellent agreement exists between the two methods, with correlation coeeficients of 0.999 for both river samples.

TABLE 6-6

COMPARISON OF POLAROGRAPHIC AND WINKLER D.O. RESULTS

Clinton River at Auburn Heights Sample

Polarographic D.O.			Winkler D.O.		
Mean mg/l	Range mg/l	No. of Samples	Mean mg/l	Range mg/l	No. of Samples
8.44	8.30-8.55	10	8.25	8.20-8.30	10
6.71	6.65-6.75	10	6.68	6.60-6.80	10
2.63	2.55-2.70	10	2.61	2.50-2.70	10

Correlation coefficient (r) = 0.999

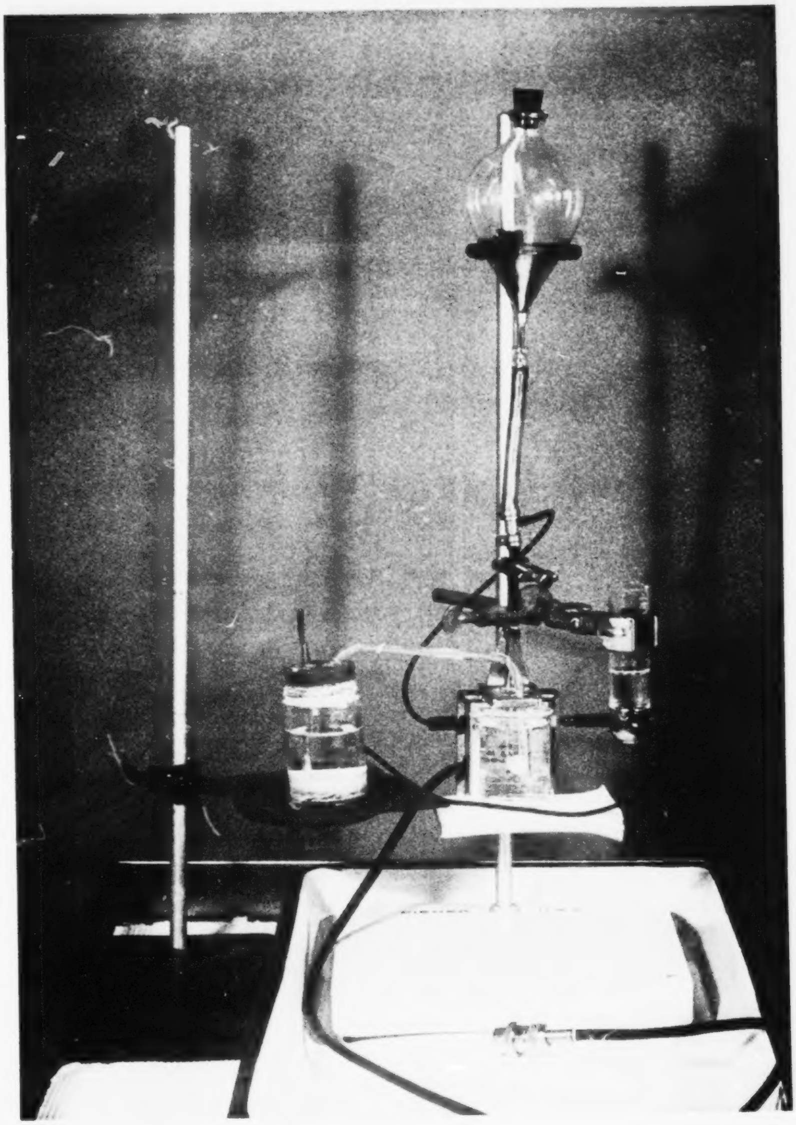


Figure 6-5. Dropping mercury electrode assembly.

TABLE 6-7

COMPARISON OF POLAROGRAPHIC AND WINKLER D.O. RESULTS

The Tittabawassee River at Smith's Crossing Sample

Polarographic D.O.			Winkler D.O.		
Mean mg/l	Range mg/l	No. of Samples	Mean mg/l	Range mg/l	No. of Samples
7.81	7.70-7.90	10	7.76	7.70-7.90	10
5.47	5.40-5.60	10	5.33	5.25-5.40	10
3.02	2.90-3.10	10	3.02	2.90-3.10	10

Correlation Coefficient (r) = 0.999

Following the development of the polarographic method using the dropping mercury electrode, it was felt that one of the newer oxygen electrodes could be used to advantage, not only in connection with the continuous BOD assembly previously discussed, but also, in connection with field survey work. After investigating several of the electrode systems either available commercially or reported in the literature, it appeared that the galvanic cell oxygen electrode as proposed by Mancy(25)(26) et al. would best meet the needs of this project. Because the electrode was not available commercially, three different size units were constructed in the instrument shop of The University of Michigan. Figure 6-6 is a photograph of one such electrode showing both the electrode and a D.C. microammeter. The cell consists of a silver-lead couple separated from the test sample by a plastic membrane. There is a direct relationship between the amount of oxygen passing the membrane and the current which is generated, which is of sufficient level to give a response on a sensitive microammeter. Thus, no external power source is needed making this ideal for field use.

Several field applications have been made, including installation in a boat for continuous river dissolved oxygen work, installation at a fixed river location for continuous D.O. monitoring at that point, activated sludge aeration tank studies, monitoring D.O. of waste treatment plant effluents, etc. Sulzer and Westgarth(27) have recently reported on the use of this instrument

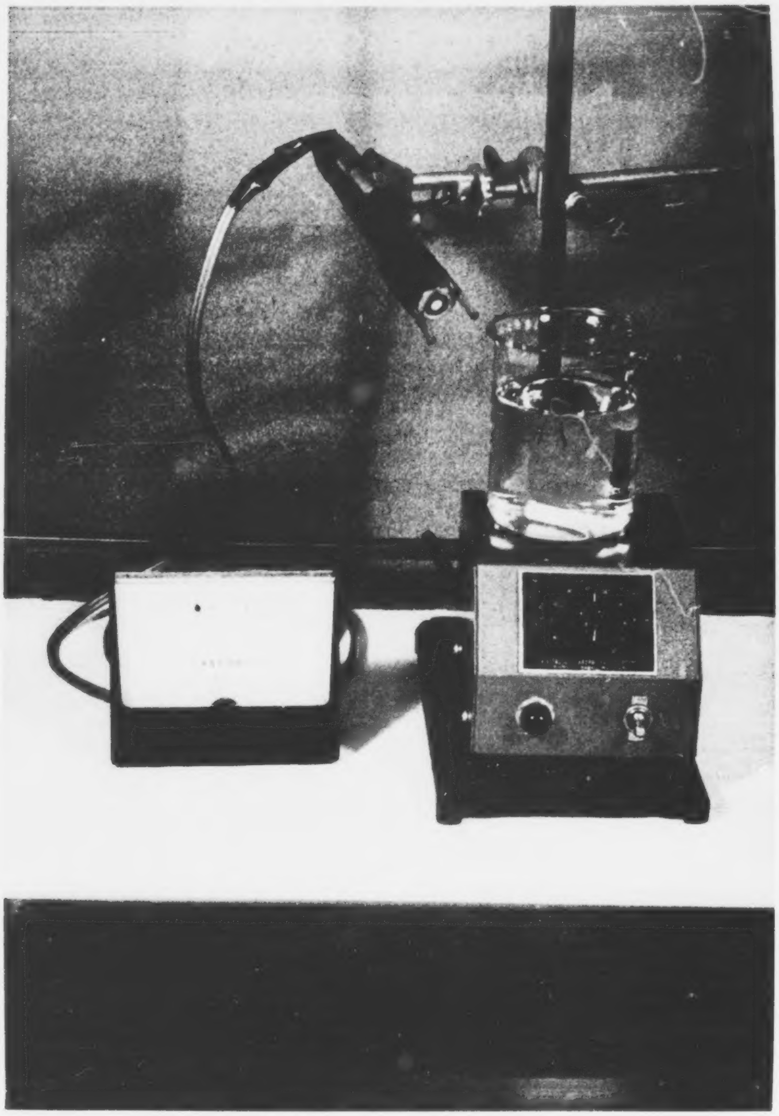


Figure 6-6. Galvanic cell oxygen electrode.

in the continuous D.O. recording in activated sludge. One of the disadvantages of the instrument for field use is the fact that it is temperature dependent, but this can be overcome by collecting samples for Winkler analysis so that the galvanic cell can be field calibrated.

During this study, the use of the galvanic cell oxygen analyzer was limited to field use or in connection with the development of the continuous BOD apparatus previously described. All laboratory D.O. determinations were made first by the Winkler method, and then in the spring and summer of 1962 by the polarographic method.

Much of the development work of the polarographic method using the dropping mercury electrode and the galvanic cell oxygen analyzer for D.O. determination was done by Mr. Joseph Schwerha, a graduate student in the Department of Environmental Health. His work is reported more fully in a research report(28) on file in this department.

SUMMARY AND CONCLUSIONS

Major reliance in this project has been placed on the reaeration procedure for conducting BOD rate studies as proposed by Elmore.(1) A discussion of the method has been presented, including the results of replication tests conducted on both Clinton River and Tittabawassee River water which suggests that the procedures employed by both this group and Elmore are the same. A comparison of reaeration and dilution BOD results is presented, indicating that in the case of Tittabawassee River water the dilution procedure gave consistently higher results, while no significant difference could be shown for the Clinton River samples.

Another factor considered has been the influence of continuous mixing on BOD results, where it was demonstrated that mixing definitely increased both BOD level and rate in the case of the Clinton River, but increased only the BOD level in the case of Tittabawassee samples. For Tittabawassee River samples it has been indicated that dilution definitely has a statistically significant influence on standard five-day BOD level, but this could not be demonstrated for Clinton River data.

Limited studies were conducted to study the influence of BOD incubation under light and dark conditions, where it was shown that oxygen was produced rather than utilized as a result of photosynthetic activity by the algae in the river water. Also evaluated was the influence of settling and filtering samples before running BOD rates, where very little difference was demonstrated except in the case of the Pontiac activated sludge effluent collected on July 17, 1962. Here, settling and filtering definitely decreased the BOD level over the non-settled sample.

As an aid in interpretation of BOD rate information, it was decided early in 1961 to attempt to evaluate the degree of nitrification occurring during the course of routine rate studies by measuring the concentration of NH_3, NO_2, and NO_3 at the beginning, the mid-point, and end of every routine BOD rate study. These data have been a great help in interpreting the BOD information, and showed that nitrification has been a definite influence in the BOD rate studies conducted on the Clinton River samples, but not on the Tittabawassee River samples.

As has been reported earlier, chlorination of the Pontiac waste treatment plant effluent caused a chlorine residual to persist in the Clinton River as far downstream as the Grand Trunk railroad bridge during low flow periods. Limited BOD rate studies conducted on chlorinated and dechlorinated samples suggested that chlorine in the concentration used might have functioned as a retarding and oxidizing agent, rather than as a sterilizing agent.

Efforts toward the development of a continuous recording BOD apparatus are reported involving a galvanic cell oxygen analyzer sealed in a respirometer cell. The apparatus is currently under development and should be operational in the near future.

Finally, consideration has been given to dissolved oxygen procedures including a comparison among analysts using the Winkler method, a comparison of polarographic and Winkler D.O. results for both the Clinton River and Tittabawassee River water samples, and a discussion of applications of the galvanic cell oxygen analyzer.

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SECTION VII

COMPARISON OF MATHEMATICAL AND GRAPHICAL EVALUATION OF BOD VELOCITY CONSTANT k_1

Over the years several mathematical and graphical procedures have been proposed for the evaluation of the BOD velocity constant k_1, assuming in each case that the monomolecular or first order reaction applied. It is the intent of this section of the report to discuss certain of these methods, and to present and discuss the results obtained by applying each method to selected rate studies conducted on samples collected from both the Tittabawassee and Clinton Rivers.

COMPUTATIONAL AND GRAPHICAL METHODS OF ANALYSIS

Computational Procedures

One of the earlier methods for the calculation of the velocity constant k_1 was that proposed by Reed and Theriault(1) which uses the least squares method--a mathematically sound and straightforward procedure. Unfortunately, the method is quite tedious to execute, and until the advent of the high speed computer it has had little appeal because of the calculating time involved. In the application of the procedure a method of successive approximations is used in which it is necessary to assume a trial value of k_1, and this is then used together with the observed data in determining a correction factor to the k_1. The operation is repeated with the corrected k_1 until the correction factor is small, or stated in another way until the assumed and the calculated value of k_1 approach one another. Obviously if the initial estimate is good the number of calculations will be less, but even if this estimate is poor the procedure will eventually arrive at a good estimate of k_1.

To facilitate the hand calculations, Theriault(1) has prepared tables that can be used for a certain range of k_1 values for data that has been collected or interpolated on an equal time interval basis. Notwithstanding these computational aids, the time necessary for hand calculation is excessive and no doubt has been a factor in the development of approximate computational and graphical procedures.

Because it is the feeling of the writer that this is the best of the computational procedures available, the effort has been taken to program the procedure on the IBM 7090 high speed computer following The University of Michigan MAD computer language. The details of the computer program are included as Appendix III to this report generally following the terminology of Theriault.(1) With this program, it is possible to include all observations rather than only those collected or interpolated on a daily basis, and to calculate the k_1 and ultimate first stage value of L. The cost for a typical series of BOD rate data was $2.00 and involved 14.7 seconds of computer time.

Because of the time involved in the hand calculations following the Reed-Theriault method, Fair(2) proposed an approximate procedure called the "log-difference" method. He felt this method would give a k_1 value which could then be used as an approximation in the Reed-Theriault method. The computational mechanics involve the use of logarithms and take about 20 minutes of time for a typical rate. Fair suggests that the "log-difference" method should be only applied to equal time intervals.

Following the lead of Fair, Thomas(3) developed another approximate procedure called the "slope" method. One advantage of this procedure over the "log-difference" method is that it can be applied to data collected over unequal time intervals as easily as to data with equal time intervals. As with the other approximate procedures, it is possible to obtain a good value for the more refined Reed-Theriault approach, and generally involves about 15 to 20 minutes of computational time for a typical rate. In subsequent work, Thomas(4) extended the "slope" method to include evaluation of any lag period, and also, to include the calculation of the probable error of the constants in the monomolecular equation.

Graphical Procedures

In an effort to further simplify the procedures for evaluation of k_1 and L, graphical and semi-graphical methods involving nomographs have been proposed. Of these, one of the earlier procedures is the "moments" method suggested by Moore, et al.,(5) which makes use of a series of prepared nomographs and a minimum amount of calculation. Unfortunately, the scope of the nomographs appearing in the original article is limited, and it has been necessary to extend one of the charts for use in this study. Also, the charts have been prepared for equal time intervals, which means that if data is collected on an irregular time basis, it becomes necessary to resort to interpolation to an equal time basis in order to use the charts. Notwithstanding these limitations, the procedure is simple and straightforward and has been used as one of the routine screening procedures for k_1 evaluation in this investigation. In a study reported in 1953 by Ludzack, et al.,(6) on the comparison of derivation procedures for BOD velocity constants, it was concluded that the "moments" method gave a better approximation to Reed-Theriault values than the "slope" method. More recently, Schroepfer, et al.,(7) in reporting at the First International Conference on Water Pollution Research on the research program on the Mississippi River in the vicinity of Minneapolis and St. Paul, concluded that the "moments" method was approximately equivalent in accuracy to the Reed-Theriault method, and therefore, was the method they used most commonly in their investigations.

In discussion of the "moments" method of Moore, a simplified graphical procedure for estimating k_1 was proposed by J. D. Lee.(8) The execution of the method involves the availability or construction, if necessary, of a series of special graph papers with time in days on the X-axis spaced according to the monomolecular reaction, and BOD in mg/l on the Y-axis. A separate grid is needed for each k_1 with the time scale spaced according to that particular k_1.

In using this method it is necessary to plot observed BOD rate information on several k_1 grids, and from these plots selecting the grid, and thereby the k_1, that gives the best straight line fit. The procedure is simple and straightforward and assumes only the availability of an adequate range of k_1 grids. All data collected at either equal or unequal times can be plotted.

In addition, the presence of a lag or immediate demand is evident and, also, the user has the opportunity of exercising professional judgment in giving less weight in fitting the line to one or more points that are obviously out of line. On the negative side, it should be pointed out that it is sometimes difficult in making a decision as to which grid gives the best straight line fit, and even with data that is consistent and truly monomolecular in nature it is usually not possible to estimate k_1 closer than to the nearest .02. In this study prior to the availability of the computer program of the Reed-Theriault method, screening of all BOD rate data was performed using Lee's grids in conjunction with the "moments" method. This combination seemed to give the best and most consistent results for the effort expended.

Another graphical method for the evaluation of the velocity constant k_1 is the "daily difference" method proposed by Tsivoglou.(9) In effect, the procedure involves a semi-log plot of the daily BOD differences on the log scale versus time on the X-scale. A line is fitted to the data by eye and from this line the slope is determined, which is the k_1 for these observations. Considerable difficulty was experienced in the application of this method to data that had observations out of line, especially in fitting a line to the semi-log plot of daily differences.

More recently, Sheehy(10) proposed the "rapid ratio" method which involves first, the determination of the ratio of each observed BOD value in a rate series to the 5-day BOD value of this same series, and then the use of published nomograms to determine a k_1 value for each ratio. If the relationship is truly monomolecular in nature, the k_1 should be the same for each ratio. On the other hand, if there are differences among the k_1 values Sheehy suggests that an average value be obtained to characterize the data. It appears that one of the main weaknesses of the method is the heavy weight given to the single 5-day BOD values, since it is used in determining all the individual ratios. On the positive side, however, is the relative simplicity of calculation, which may be an appealing feature to some users.

SELECTED ILLUSTRATIONS

In an effort to show the influence of the method of analysis on the resulting velocity constant k_1, typical rate data was selected from both the Tittabawassee and Clinton River samples, and each of the methods previously discussed was used in analyzing the same data. In the laboratory, the jug reaeration technique as proposed by Elmore(11) was used in all cases, and the samples were incubated at 20°C.

Tittabawassee River Rates

Rate information determined on samples collected during the August, 1961 intensive survey, which included samples of the Dow Chemical Company waste treatment plant effluent, Tittabawassee River at Smith's Crossing, and Tittabawassee River at Freeland, was subjected to the various methods of analysis. In addition, rate information determined on a sample of the Tittabawassee River at Smith's Crossing collected on June 18, 1962 was similarly analyzed because of the high BOD level involved, which is unusual for this sampling station. Apparently some waste had bypassed the Dow treatment plant on this day resulting in a generally elevated river BOD situation. No noticeable adverse effect was observed in terms of the oxygen balance of the river because of high river runoff conditions, but it did prove to be an interesting study situation from the standpoint of the BOD rate.

Figure 7-1 is a plot of the BOD rate information determined on a 24-hour composite sample of the Dow Chemical Company waste treatment plant effluent collected on August 24, 1961. Figure 7-1(a) is a linear plot of BOD versus time while Figures 7-1(b), (c), and (d) are plots on Lee's grids for k_1 of .01, .02, and .04 respectively. Table 7-1 is a listing of the resulting k_1 values obtained by applying the several methods of analysis to this data.

It is apparent from Table 7-1 that the value of k_1 obtained from the same data might vary from .0101 to .0433 depending on the method of analysis used. In some cases the procedure called for equal time interval data, and where this was the situation, it was necessary to obtain values by interpolating on a linear basis.

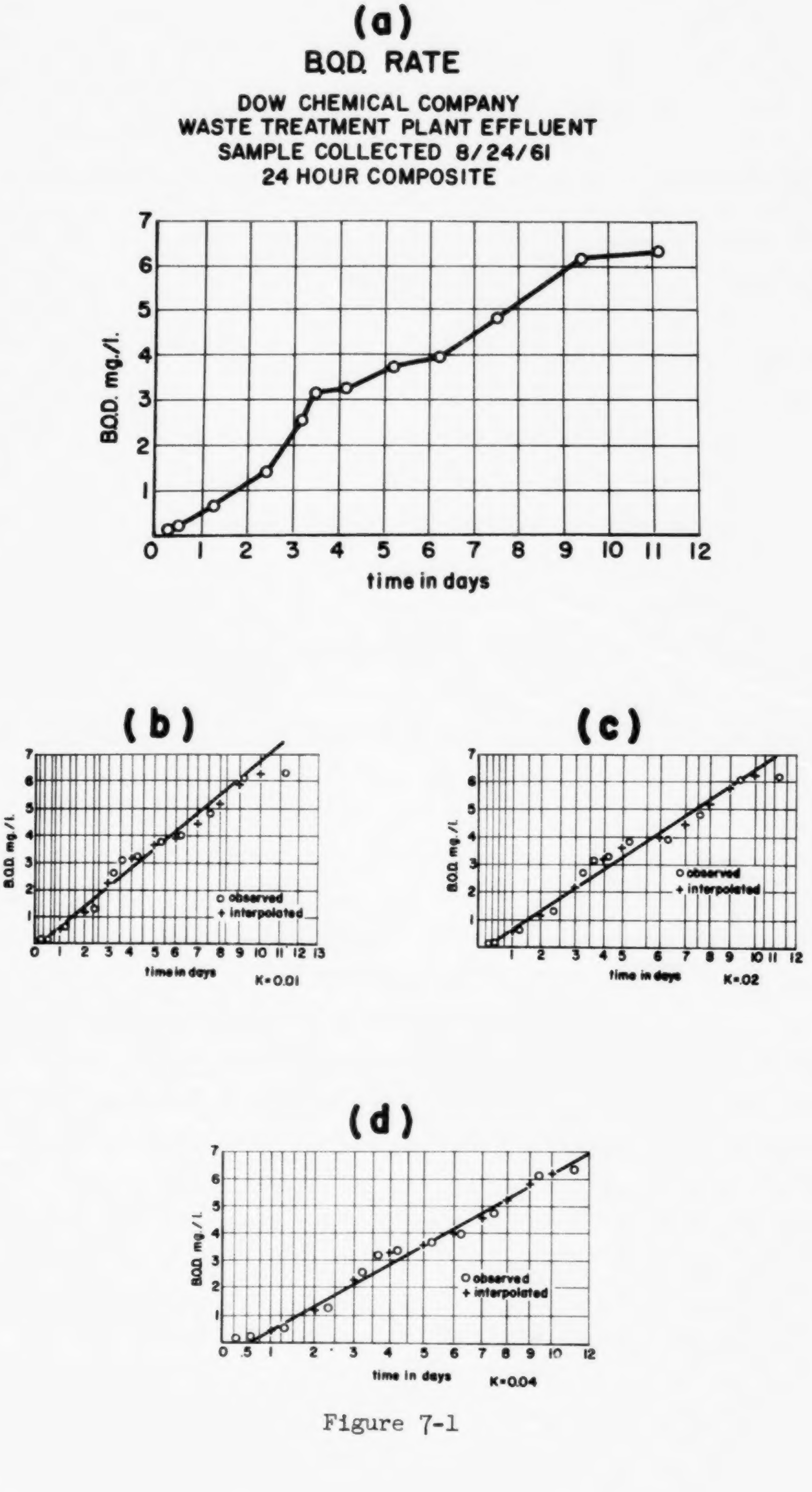
(a)
B.O.D. RATE
DOW CHEMICAL COMPANY
WASTE TREATMENT PLANT EFFLUENT
SAMPLE COLLECTED 8/24/61
24 HOUR COMPOSITE
B.O.D. mg./l.
time in days
(b)
o observed
+ interpolated
K=0.01
(c)
o observed
+ interpolated
K=.02
(d)
o observed
+ interpolated
K=0.04

Figure 7-1

The equal time interpolated results are indicated as such on the Lee's plots of Figure 7-1.

TABLE 7-1

DOW WASTE TREATMENT PLANT EFFLUENT

Sample Collected August 24, 1961

Method	k_1
Reed-Theriault (Unequal time interval)	.0309
Reed-Theriault (Equal time interval)	.0221
Slope (Equal time interval)	.0197
Slope (Unequal time interval)	.0101
Moments* (Equal time interval)	.0200
Rapid Ratio (Equal time interval)	.0433
Daily Difference (Equal time interval)	.0261
Log Difference (Equal time interval)	.0172
Lee (Unequal time interval)	.0400

*Using 1, 2, 3, 4, 5, 6, and 7-day sequence.

Figure 7-2 is a plot of the BOD rate information determined on a sample of the Tittabawassee River at Smith's Crossing collected on August 24, 1961. Figure 7-2(a) is a linear plot of BOD versus time while Figures 7-2(b), (c), and (d) are plots on Lee's grids for k_1 of .04, .06, and .08 respectively. Table 7-2 is a listing of the resulting k_1 values obtained by applying the several methods of analysis to this data.

Here again it is apparent the k_1 might vary from .0560 to .0800 depending on the method of analysis used.

Figure 7-3 is a plot of the BOD rate information determined on a sample of theTittabawassee River at Freeland collected on August 24, 1961. Figure 7-3(a) is a linear plot of BOD versus time while Figures 7-3(b), (c), and (d) are plots of Lee's grids for k_1 of .01, .02, and .04 respectively. Table 7-3 is a listing of the resulting k_1 values obtained by applying the several methods of analysis to this data.

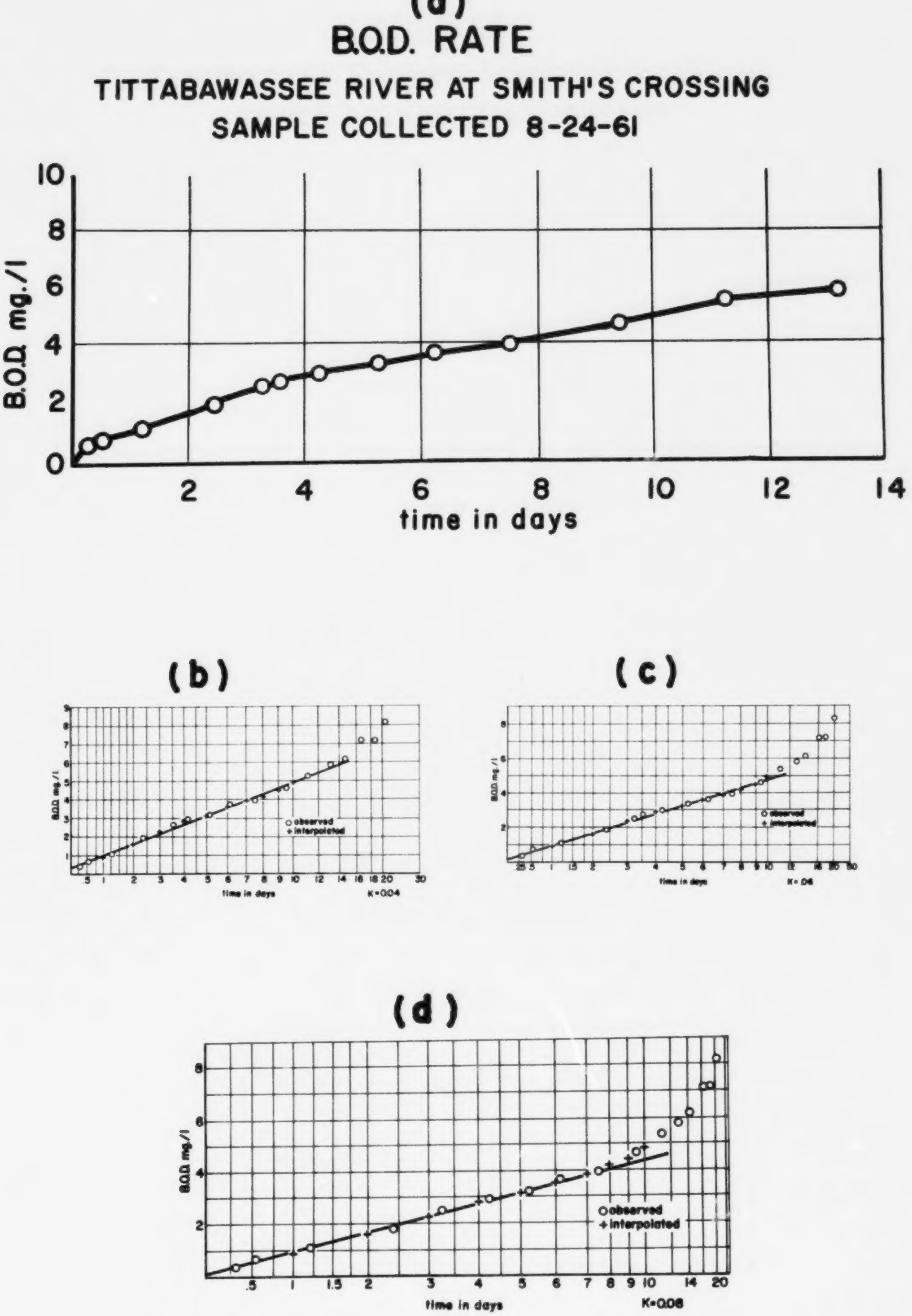
(a)
B.O.D. RATE
TITTABAWASSEE RIVER AT SMITH'S CROSSING
SAMPLE COLLECTED 8-24-61
B.O.D. mg./l
0
2
4
6
8
10
time in days
2
4
6
8
10
12
14
(b)
B.O.D. mg./l
○ observed
+ interpolated
time in days
K=0.04
(c)
B.O.D. mg./l
○ observed
+ interpolated
time in days
K=.06
(d)
B.O.D. mg./l
○ observed
+ interpolated
time in days
K=0.08

Figure 7-2

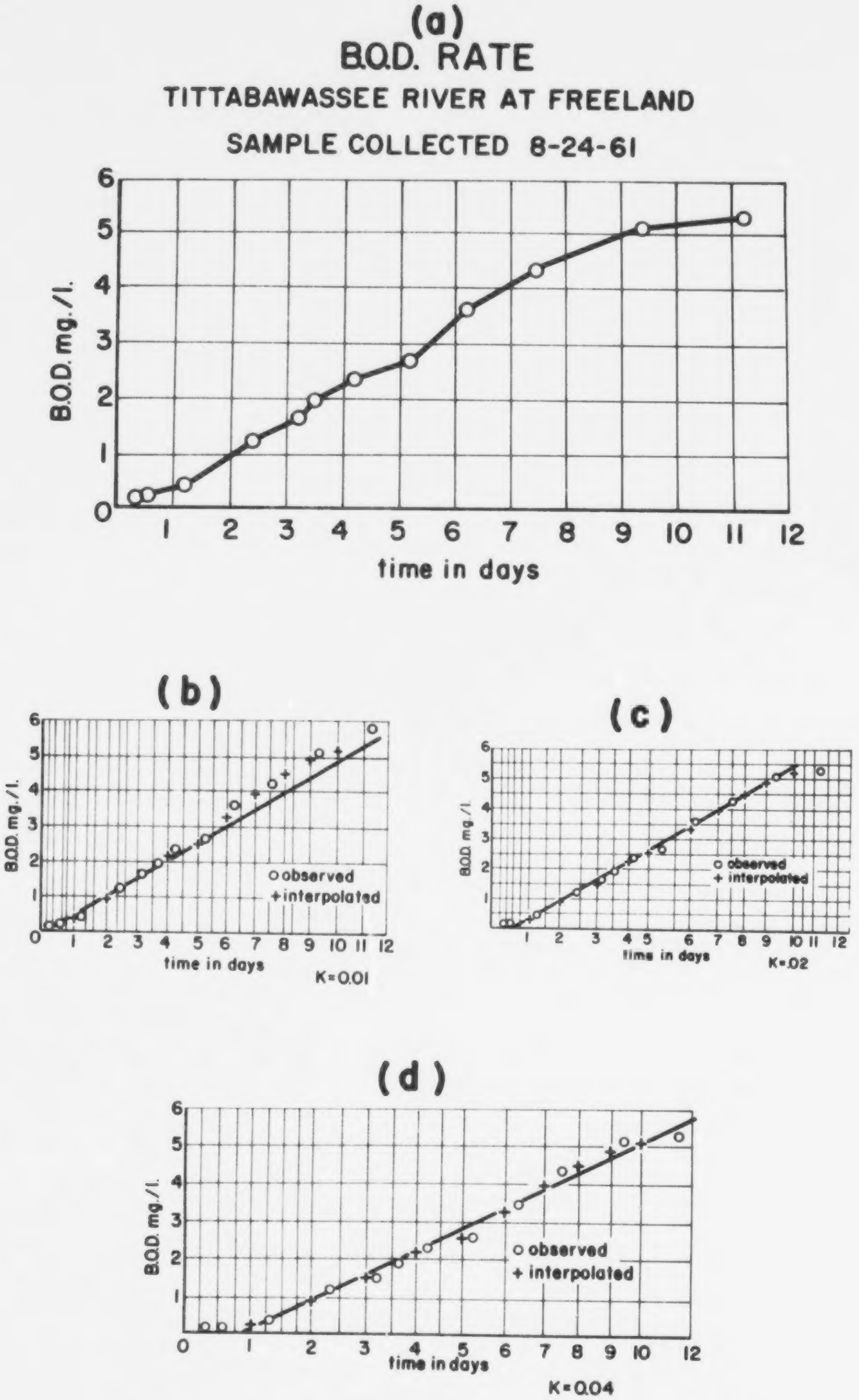
(a)
B.O.D. RATE
TITTABAWASSEE RIVER AT FREELAND
SAMPLE COLLECTED 8-24-61
B.O.D. mg./l.
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
9
10
11
12
time in days
(b)
o observed
+ interpolated
time in days
K=0.01
(c)
o observed
+ interpolated
time in days
K=.02
(d)
o observed
+ interpolated
time in days
K=0.04

Figure 7-3

TABLE 7-2

TITTABAWASSEE RIVER AT SMITH'S CROSSING

Sample Collected August 24, 1961

Method	k_1
Reed-Theriault (Unequal time interval)	.0636
Reed-Theriault (Equal time interval)	.0669
Slope (Equal time interval)	.0560
Slope (Unequal time interval)	.0750
Moments* (Equal time interval)	.0700
Rapid Ratio (Equal time interval)	.0744
Daily Difference (Equal time interval)	.0720
Log Difference (Equal time interval)	.0577
Lee (Unequal time interval)	.06 to .0800

*Using 1, 2, 3, 4, 5, 6, and 7-day sequence.

TABLE 7-3

TITTABAWASSEE RIVER AT FREELAND

Sample Collected August 24, 1961

Method	k_1
Reed-Theriault (Unequal time interval)	.0129
Reed-Theriault (Equal time interval)	.0020
Slope (Equal time interval)	.0113
Slope (Unequal time interval)	-.0002
Moments* (Equal time interval)	small minus value
Rapid Ratio (Equal time interval)	.0089
Daily Difference (Equal time interval)	.0210
Log Difference (Equal time interval)	.0232
Lee (Unequal time interval)	.0200

*Using 1, 2, 3, 4, 5, 6, and 7-day sequence.

As with the previous illustrations, it is seen the k_1 might vary from -.0002 to .0232 depending on the method of analysis used.

Unfortunately, no nitrogen determinations were made during the August, 1961 intensive survey on the Tittabawassee River, but determinations on other river samples during the summer of 1961 indicated that very rarely was there nitrification during the first 14 days of a rate. No adequate explanation is available as to why the k_1 rates of the Smith's Crossing and Freeland samples were significantly different during the same sampling period.

Figure 7-4 is a plot of the BOD rate information determined on a sample of the Tittabawassee River at Smith's Crossing collected on June 18, 1962. Figure 7-4(a) is a linear plot of BOD versus time while Figures 7-4(b), (c), (d), and (e) are plots of Lee's grids for k_1 = 0.1, 0.12, 0.14, and 0.16 respectively. Table 7-4 is a listing of the resulting k_1 values obtained by applying the several methods of analysis to this data.

TABLE 7-4

TITTABAWASSEE RIVER AT SMITH'S CROSSING

Sample Collected June 18, 1962

Method	k_1
Reed-Theriault (Equal time interval)	.1393
Slope (Equal time interval)	.1445
Slope (Unequal time intervals)	.1525
Moments* (Equal time interval)	.1600
Rapid Ratio (Equal time interval)	.1440
Daily Difference (Equal time interval)	.1070
Log Difference (Equal time interval)	.0975
Lee (Unequal time interval)	.1200

*Using 1, 2, 3, 4, 5, 6, and 7-day sequence.

Inspection of Table 7-4 indicates the k_1 might range from .0975 to .1600 depending on the method of analysis used. As indicated previously, an unusual situation prevailed on June 18, 1962 in that the BOD level was much higher than usual at this station as a result of waste bypassing the Dow treatment plant. It is interesting too, that the k_1 rate is much higher than during

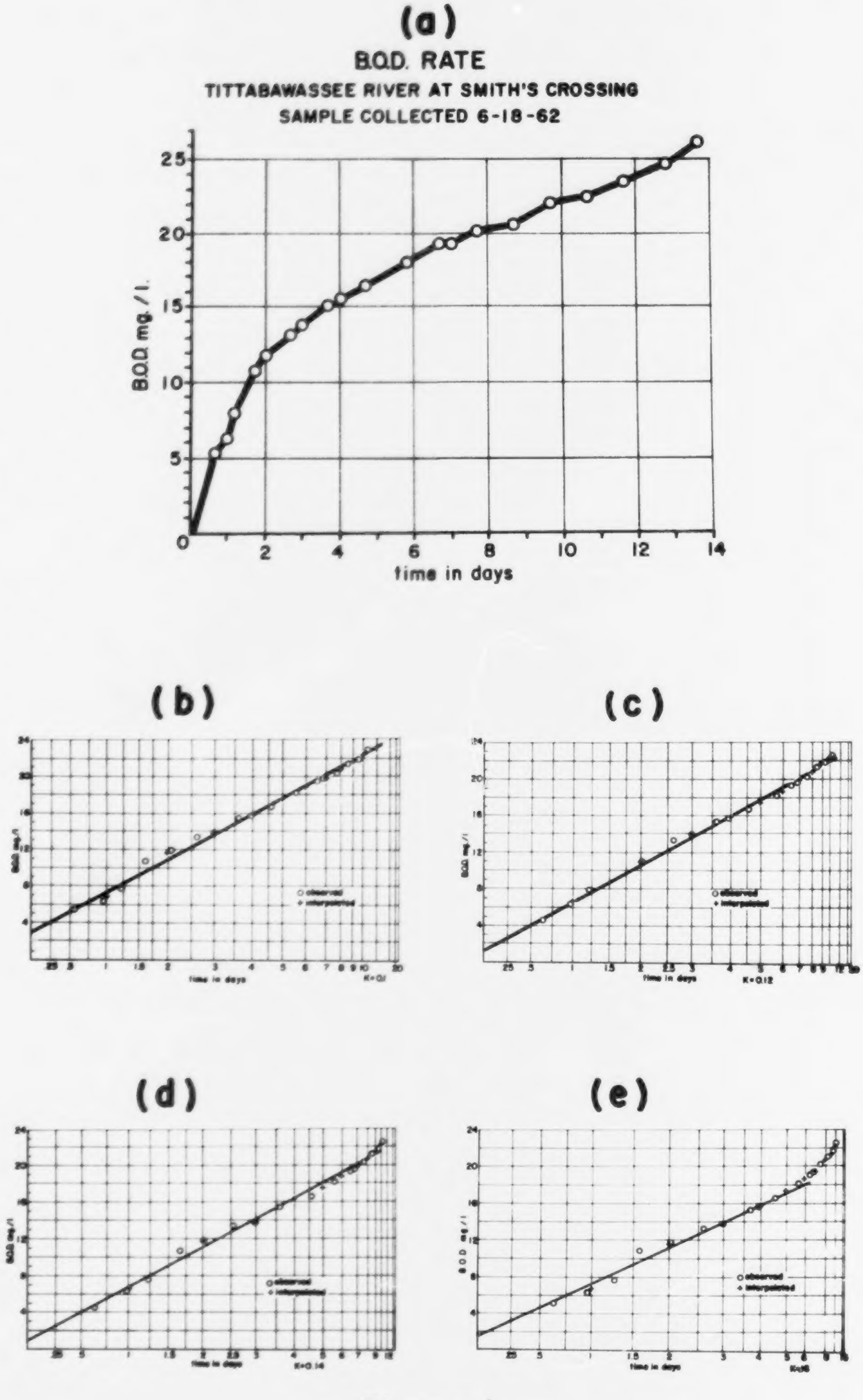
(a)
B.O.D. RATE
TITTABAWASSEE RIVER AT SMITH'S CROSSING
SAMPLE COLLECTED 6-18-62
B.O.D. mg./l.
time in days
(b)
observed
interpolated
time in days
K=0.1
(c)
observed
interpolated
time in days
K=0.12
(d)
observed
interpolated
time in days
K=0.14
(e)
observed
interpolated
time in days

Figure 7-4

the August, 1961 survey when the river was only receiving treated effluent from the Dow plant. This certainly is suggestive that biological treatment removes most of the readily available nutrients, and thereby reduces the k_1 rate of biologically treated effluents. In addition to the higher k_1 rate of the June 18, 1962 sample, a fine flocculent material was observed dispersed throughout the sample, which when viewed microscopically was seen to contain a mass of rod shaped organisms suggestive of Sphaerotilus natans. With the exception of one winter sampling run, this was the only time such a floc was observed at this station during the approximately two years of sampling. It indicates that given the proper nutrient conditions a biological floc can easily develop in the Tittabawassee River. No significant nitrification occurred during the 14 days this rate was run based on nitrogen determinations made at the beginning, the midpoint, and the end of the rate.

Clinton River Rates

For the Clinton River only one rate was subjected to the various methods of k_1 determination, namely, a sample of the Clinton River collected at Auburn Heights on July 27, 1961.

Figure 7-5 is a plot of the BOD rate information determined on this sample. Figure 7-5(a) is a linear plot of BOD versus time while Figures 7-5(b), (c), (d), and (e) are plots on Lee's grids for k_1 of .01, .02, .04 and .06 respectively. It is readily apparent from an inspection of Figure 7-5(a) that a two-stage relationship is present, and supplementary nitrogen information indicates that active nitrification was taking place after six days. Three separate groupings of the data were made: (1) the first stage including the first five days, (2) the second stage from the sixth day forward, and (3) all the data from the beginning through the 14th day to illustrate what would result if no distinction was made between the first and second stage.

Table 7-5 is a listing of the resulting k_1 values obtained by applying the several methods of analysis to the first stage of the data including the first five days.

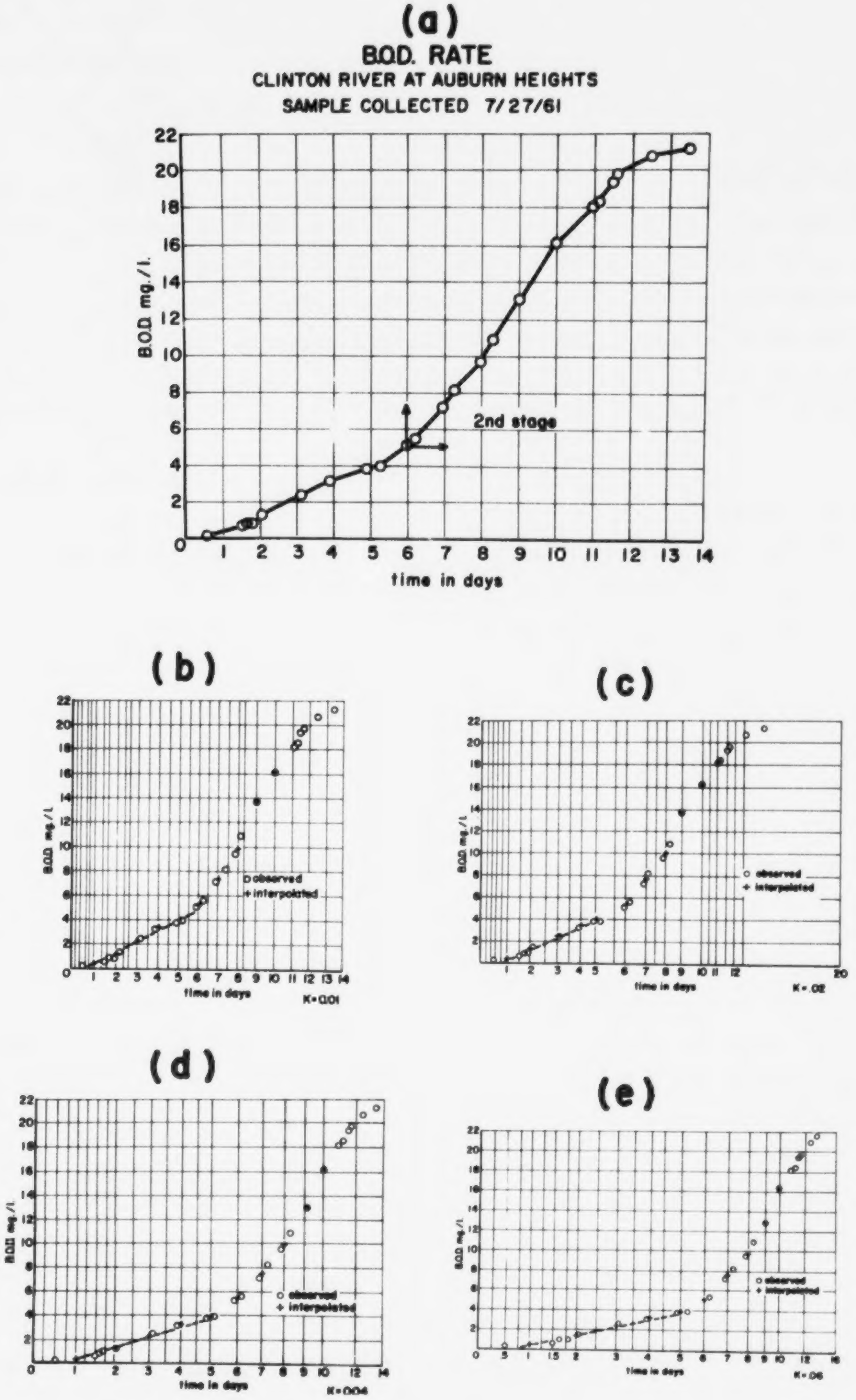
(a)
B.O.D. RATE
CLINTON RIVER AT AUBURN HEIGHTS
SAMPLE COLLECTED 7/27/61
B.O.D. mg./l.
2nd stage
time in days
(b)
B.O.D. mg./l.
observed
interpolated
time in days
K=0.01
(c)
B.O.D. mg./l.
observed
interpolated
time in days
K=.02
(d)
B.O.D. mg./l.
observed
interpolated
time in days
K=0.04
(e)
B.O.D. mg./l.
observed
interpolated
time in days
K=.06

Figure 7-5

TABLE 7-5 - FIRST STAGE

CLINTON RIVER AT AUBURN HEIGHTS

Sample Collected July 27, 1961

Method	k_1
Reed-Theriault (Equal time interval)	.0194
Slope (Equal time interval)	.0080
Moments (Equal time interval)	$<$.0100
Rapid Ratio (Equal time interval)	.0050
Daily Difference (Equal time interval)	.0430
Log Difference (Equal time interval)	.0210
Lee (Unequal time interval)	.0100 to .0400

It is apparent from Table 7-5 that at these very low k_1 rate levels none of the methods are very satisfactory.

Figure 7-6 is a plot of the second stage BOD rate information plotted on various Lee grids. Figure 7-6(a) is for a k_1 grid of .01, Figure 7-6(b) for a k_1 grid of .02, Figure 7-6(c) for a k_1 grid of .04, and Figure 7-6(d) for a k_1 grid of .06. Table 7-6 is a listing of the resulting k_1 values obtained by applying the several methods of analysis to the second stage results starting with the 6th day.

TABLE 7-6 - SECOND STAGE

CLINTON RIVER AT AUBURN HEIGHTS

Sample Collected July 27, 1961

Method	k_1
Reed-Theriault (Equal time interval)	.0278
Slope (Equal time interval)	.0221
Slope (Unequal time interval)	.0211
Moments (Equal time interval)	$<$.0100
Rapid Ratio (Equal time interval)	.0330
Daily Difference (Equal time interval)	.0270
Log Difference (Equal time interval)	.0437
Lee (Unequal time interval)	.0400

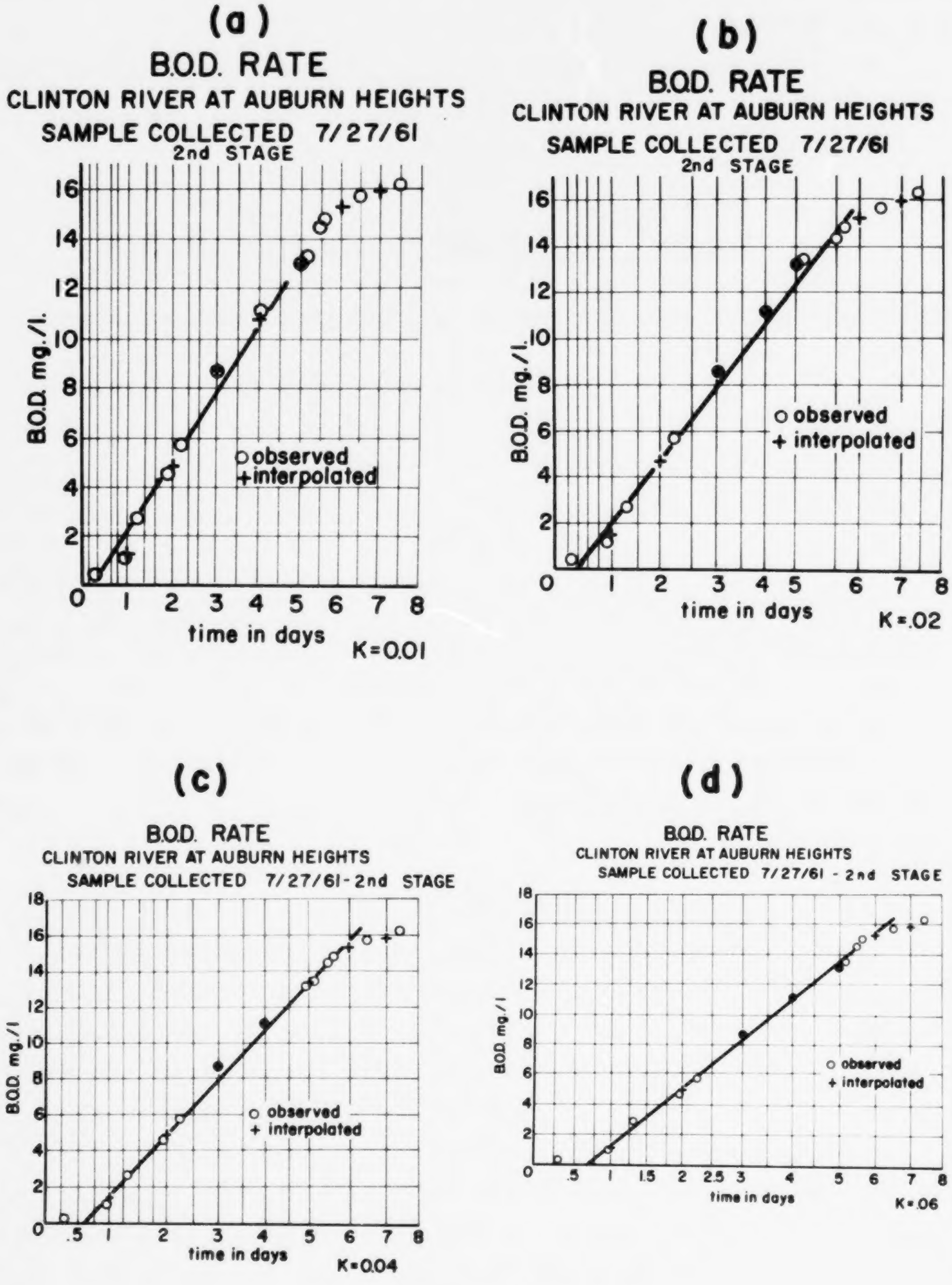
(a)
B.O.D. RATE
CLINTON RIVER AT AUBURN HEIGHTS
SAMPLE COLLECTED 7/27/61
2nd STAGE
B.O.D. mg./l.
time in days
○ observed
+ interpolated
K=0.01
(b)
B.O.D. RATE
CLINTON RIVER AT AUBURN HEIGHTS
SAMPLE COLLECTED 7/27/61
2nd STAGE
B.O.D. mg./l.
time in days
○ observed
+ interpolated
K=.02
(c)
B.O.D. RATE
CLINTON RIVER AT AUBURN HEIGHTS
SAMPLE COLLECTED 7/27/61 - 2nd STAGE
B.O.D. mg./l
time in days
○ observed
+ interpolated
K=0.04
(d)
B.O.D. RATE
CLINTON RIVER AT AUBURN HEIGHTS
SAMPLE COLLECTED 7/27/61 - 2nd STAGE
B.O.D. mg./l
time in days
○ observed
+ interpolated
K=.06

Figure 7-6

Here more consistency is noted than in the case of the first stage but there is still variation among the results using the various methods.

Finally, Table 7-7 is a listing of the resulting k_1 values obtained by applying the several methods to all the data.

TABLE 7-7 - ALL RESULTS

CLINTON RIVER AT AUBURN HEIGHTS

Sample Collected July 27, 1961

Method	k_1
Reed-Theriault (Equal time interval)	-.998
Moments (Equal time interval)	$<$ .010
Rapid Ratio (Equal time interval)	$<$ .010
Daily Difference (Equal time interval)	$<$ .010
Log Difference (Equal time interval)	-1.050
Lee (Unequal time interval)	.01 to .040(5 days)

It is apparent from Table 7-7 that none of the methods give a satisfactory result when applied to a two-stage curve as illustrated in Figure 7-5(a).

DISSCUSSION

The following questions might be legitimately raised--(1) What is the best computational or graphical procedure for evaluating the BOD velocity constant k_1 from a series of observed BOD results? and (2) Is the monomolecular formulation the best mathematical expression to be applied to all BOD reactions?

Looking at the first question, it is the opinion of the writer that an initial step should be a linear plot of BOD versus time. Such a plot will serve to identify immediately any abnormalities that may be present in the form of a 2-stage demand, an initial lag or immediate demand, or one or more points which are obviously out of line. This, then, will enable the investigator to decide what part of the data will be used in any subsequent graphical or computational methods of analysis. Experienced workers have indicated they could make a good estimate of the k_1 rate by merely looking at different sections of the linear plot.

If it is necessary to perform all calculations by hand, it appears that a combination of Lee's grid and "moments" methods gives the best results for the effort expended. On the other hand, if a high speed computer is available, then the Reed-Theriault program would be the method of choice.

Looking at the second question as to the appropriateness of the monomolecular formulation for all BOD reactions, it is the feeling of the writer that more exploratory work is needed along these lines. Certainly it appears that in dealing with raw or partially treated waste the monomolecular formulation reasonably defines observed data. However, in dealing with biologically treated effluents such as those discharging into the Clinton and Tittabawassee Rivers there may be more appropriate mathematical expressions available.

Where nitrification is a problem such as in Figure 7-5 relating to a sample of the Clinton River collected at Auburn Heights on July 27, 1961, the situation becomes even more complicated. It appears that here a condition exists of a retarded first stage reaction resulting from the availability of relatively resistant nutrients, followed by a rapid second stage reaction resulting from nitrification, and then a return to the relatively slow rate observed in the first stage.

Most of the Clinton River BOD rate reactions seemed to follow this typical S-type curve. It is not the intent to discuss here the matter of nitrification but to reserve it for another section of this report.

Other investigators, notably Busch and his associates,(12)(13)(14) have raised the question as to the appropriateness of the monomolecular reaction to describe all BOD progressions.

SUMMARY AND CONCLUSIONS

Several mathematical and graphical procedures for the evaluation of the BOD velocity constant k_1 have been discussed, assuming in each case that the monomolecular or first order reaction applied. In addition, comparisons have been presented of the results obtained by applying each method to the same rate studies conducted on selected samples collected from both the Clinton and Tittabawassee Rivers.

It has been recommended that a first step in the analysis of BOD rate information should be a linear plot of BOD versus time for the evaluation of any abnormalities. Following this, it appears that a combination of the Lee grid and "moments" methods gives the best results for the effort expended; if a high speed computer is available, the Reed-Theriault program would be recommended.

While recourse is had to computational and graphical procedures, the investigator must not abandon professional judgment in the blind application of any method.

ACKNOWLEDGEMENTS

The laboratory work was performed under the supervision of Mr. Jackson R. Pelton. Certain of the calculations were performed by Mr. James R. Herman, while the Reed-Theriault procedure was programmed by Thomas D. Downs.

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SECTION VIII

TIME OF PASSAGE DETERMINATION IN INLAND STREAMS

with
Jackson R. Pelton

One of the important elements necessary for an accurate evaluation of the self-purification capacity of a river where one or more different types of wastes may exist such as organic, bacteriological, or chemical contaminants, is the time of flow or passage along the stream. Such information assumed particular importance in this project because of specific interest in the river BOD removal rate k_r, which is determined from 5-day BOD samples taken at river sampling stations together with the time of travel between these sampling stations. Adequate time of passage data may be obtained or estimated in several ways, including calculation on a displacement basis from a knowledge of the channel characteristics together with the prevailing runoff or, possibly, by means of an internal or external tracer such as a dye.

This section of the report will consider both the displacement calculation and tracer techniques, including the application of both procedures for time of passage determinations under selected conditions for the Clinton and Tittabawassee Rivers.

Displacement Calculations

Where the river channel is of a fairly uniform character, time of passage can be calculated for a given runoff on a displacement basis from a knowledge of the runoff together with the corresponding river volume. This presumes that information is available on the river channel characteristics so that accurate volumes can be calculated for a given runoff level. Sometimes this data is available from another source such as the files of the Corps of Engineers covering flood protection or navigation studies, or, it may be necessary to collect it in the field. If this is the case, adequate definition of channel characteristics can generally be obtained by cross sectioning the relevant river stretches at about 500-foot intervals. This need not be done with a high degree of accuracy, but rather, emphasis should be placed on more frequent soundings wherever possible. It may be accomplished by means of a tape and sounding rod or weighted line, together with a good map for location and orientation in the field, or if considerable cross section work is anticipated, it might be desirable to obtain a portable recording fathometer which gives a continuous record of channel depth.

Volumes can be calculated on an average end area basis with adjustment to various runoff levels made by means of an appropriate rating curve. This approach can be programmed for high speed digital computers, and incorporated as a part of a more extensive program as that described in Section X of this report.

For both the Clinton and Tittabawassee Rivers, the Michigan Water Resources Commission made available cross section information at about 500-foot intervals through the critical section of both rivers, thereby saving the project personnel considerable field effort.

Tracer Techniques

As an adjunct, or under some circumstances as replacement for the computational methods of arriving at time of passage estimates, certain types of tracer studies may reveal the required information. Tracer materials may be classified as internal or external, where an internal tracer could be defined as some constituent of a waste source which can be varied in concentration and which could be easily measured in the stream such as chlorides, etc., while an external tracer could be defined as anything which can be added to the stream and then easily followed and measured such as salt, dye, radioactive material, etc.

Internal tracers that have been utilized, and the common techniques that have been applied in their respective measurement, are summarized in Table 8-1.

Different types of external tracers have been used with varying degrees of success, including such things as floats, salts, materials that would change the pH, and highly colored organic pigments. Several investigators have recently reported on tracer methodology, including the work of Pritchard and Carpenter(1) on Conowingo Reservoir, Baltimore Harbor and Chesapeake Bay, Md., the work of Carpenter(2)(3) on Baltimore Harbor, Md., the work of

Pearson(4) on San Francisco Bay, Calif., the work of Selleck and Pearson(5) on San Francisco Bay, Calif., the work of Nickerson(6) on Babson Reservoir, Mass., the work of Noble and Ayers(7) on Little Traverse Bay, Michigan, and the work of Hull(8) on the American River in California.

TABLE 8-1

COMMON INTERNAL TRACERS AND MEANS OF DETECTION AND MEASUREMENT USED IN STREAM TIME OF PASSAGE STUDIES

Tracer as Waste Constituent	Means of Detection
Acid or Alkaline	pH Measurement, Acidity or Alkalinity Determination
Highly Colored Waste	Colorimetric or Spectrophotometric Determination
Highly Ionized Chemical Waste	Electrical Conductivity Determination or Specific Ion Determination
Highly Turbid Waste	Turbidimetric Determination
Waste having High Chemical Oxygen Demand	Measuring O_2 Consumed (COD Test)

The two types of tracers that have shown most promise for use in natural waters are radiochemical tracers and fluorescent organic pigments. Due to the high cost of radiochemical compounds, the equipment needed for their detection, hazards in handling, and public opposition to the planned addition of radiation to the environment, the use of radiochemical tracers in natural waters has been limited. Among the fluorescent dyes that have been used in water tracing studies, fluorescein has probably been employed most widely. However, it has certain limitations because of its exceedingly high photochemical decay rate and natural background levels. More recently, Rhodamine B and Pontacyl Brilliant Pink B fluorescent dyes have been used for tracing work in natural waters. Feverstein and Selleck(9) reported on a laboratory investigation designed to determine the behavior of the fluorescent tracers fluorescein, Rhodamine B, and Pontacyl Brilliant Pink B in waters of various quality, along with an economic evaluation of these dyes. The choice of a tracer material is based on the following features: 1) sensitivity and ease of quantitative detection; 2) resolution of the tracer material from naturally occurring substances; 3) low rates of chemical or photochemical degradation; 4) low physical adsorption to suspended sediments, algae or aquatic vegetation; and 5) cost, ease of handling and a low degree of potential hazard to man or aquatic life.

Comparisons were made between Rhodamine B and Pontacyl Brilliant Pink B dyes during the summer of 1963 for tracer use in inland streams, and based on this experience including relative cost, it appears that Rhodamine B dye has the greater advantage. This dye used in conjunction with a Turner Model 111 Fluorometer could be detected in as low a concentration as 0.1 part per billion. This, of course, is substantially below the visual detection limit, meaning the dye would not be apparent to casual onlookers.

In practical field use it became necessary to calibrate the fluorometer in the laboratory, and then to estimate the amount of dye needed in the river on the basis of the anticipated dilution in accordance with river flow. Generally it was necessary to add a new dye charge at each bridge sampling station, and, also, to work upstream to avoid the possible confusion of monitoring more than one upstream dye charge at a given station.

CASE ILLUSTRATIONS

Because of the importance of time of passage information to this investigation, efforts were directed toward obtaining as accurate an estimate as possible for both the Clinton River and Tittabawassee River study areas. As an initial effort, time of passage was calculated for both rivers on a displacement basis, and then later checked in the field using Rhodamine B dye as an external tracer, with the dye studies successful only in the case of the Tittabawassee River. The results of these undertakings will be presented in the following sections of this report.

Clinton River, Michigan

The availability of cross section data for the critical section of the Clinton River, supplied by the Michigan Water Resources Commission, greatly facilitated this phase of the study. Using this information, time of passage was calculated by means of the displacement method previously described, for a runoff level of 33 cfs, which, of course, was the prevailing runoff during the August 23-25, 1960 intensive water quality survey. These results are presented in Table 8-2 where it is seen that the total time from the Pontiac waste treatment plant outfall to sampling station 8 in Rochester is 0.86 days.

On August 14, 1962 an effort was made to conduct an external tracer study using Rhodamine B dye, but unfortunately, due to the limited availability of a fluorometer it was not possible to collect meaningful data. Times of first detection were measured to several of the sampling stations, but it was not possible to monitor the dye long enough at each station to determine the mean time of passage. It is this figure rather than the time of first detection, which should be compared with the calculated time using the displacement approach.

TABLE 8-2

COMPUTED TIME OF PASSAGE DATA

Clinton River

Runoff Level - 33 cfs

Sampling Station	Location	Mile Point	Computed Time in Days
	Pontiac Waste Treatment Plant	46.39	0.00
	Grand Trunk Railroad Bridge	45.74	0.08
2	M-59 Bridge	44.87	0.15
3	Auburn Heights	43.37	0.27
4	Squirrel Road	42.99	0.29
5	Hamlin Road	41.95	0.39
6	Adams Road	39.78	0.58
7	Livernois Road	36.27	0.79
8	Rochester	34.98	0.86

Tittabawassee River, Michigan

As with the Clinton River, cross section data for the critical section of the Tittabawassee River from Midland to Saginaw was supplied by the Michigan Water Resources Commission. With this information, time of passage was calculated by means of the displacement method for the runoff level of 346 cfs prevailing during the August 23-25, 1961 survey period.

In addition to the calculated time, a special field survey for a time of passage measurement was conducted during the period August 15-16, 1962, when the river was stabilized at a drought flow level by storing water in Sanford Reservoir on the main Tittabawassee River above Midland. This was arranged by the Dow Chemical Company and provided an opportunity to supplement the water quality data collected under similar conditions in the summer of 1961. Time was measured by means of Rhodamine B dye together with a Turner Model 111 Fluorometer.

Figure 8-1 is a copy of the gage chart for the Midland gage on the Tittabawassee River covering the period August 8 - 16, 1962. It is seen that during the survey period of August 15-16, 1962 the river flow was steady except for a peak about midday on August 16, 1962. This peak did not influence the dye studies which were being completed at this time near Saginaw in the lower river. All of the upper river, from Midland to Freeland, was studied on August 15, 1962 under steady flow conditions.

The U.S.G.S. gage at Midland does not measure all of the flow in the lower river because of diversion of some of the river water by the Dow Chemical Company. From a knowledge of the diversions reported by Dow, it has been possible to estimate the total river flow below Midland as listed in Table 8-3.

TABLE 8-3

RIVER FLOWS IN TITTABAWASSEE RIVER BELOW MIDLAND, MICH.

August 15, 1962

U.S.G.S. Stream Gage	220 cfs
Dow Treatment Plant Effluent	76.2 cfs
Drain A	13.4 cfs
Drain B	5.3 cfs
Total River Flow below Dow	314.9 cfs

GAGE CHART

TITTABAWASSEE RIVER AT MIDLAND

AUGUST 8 – AUGUST 16, 1962

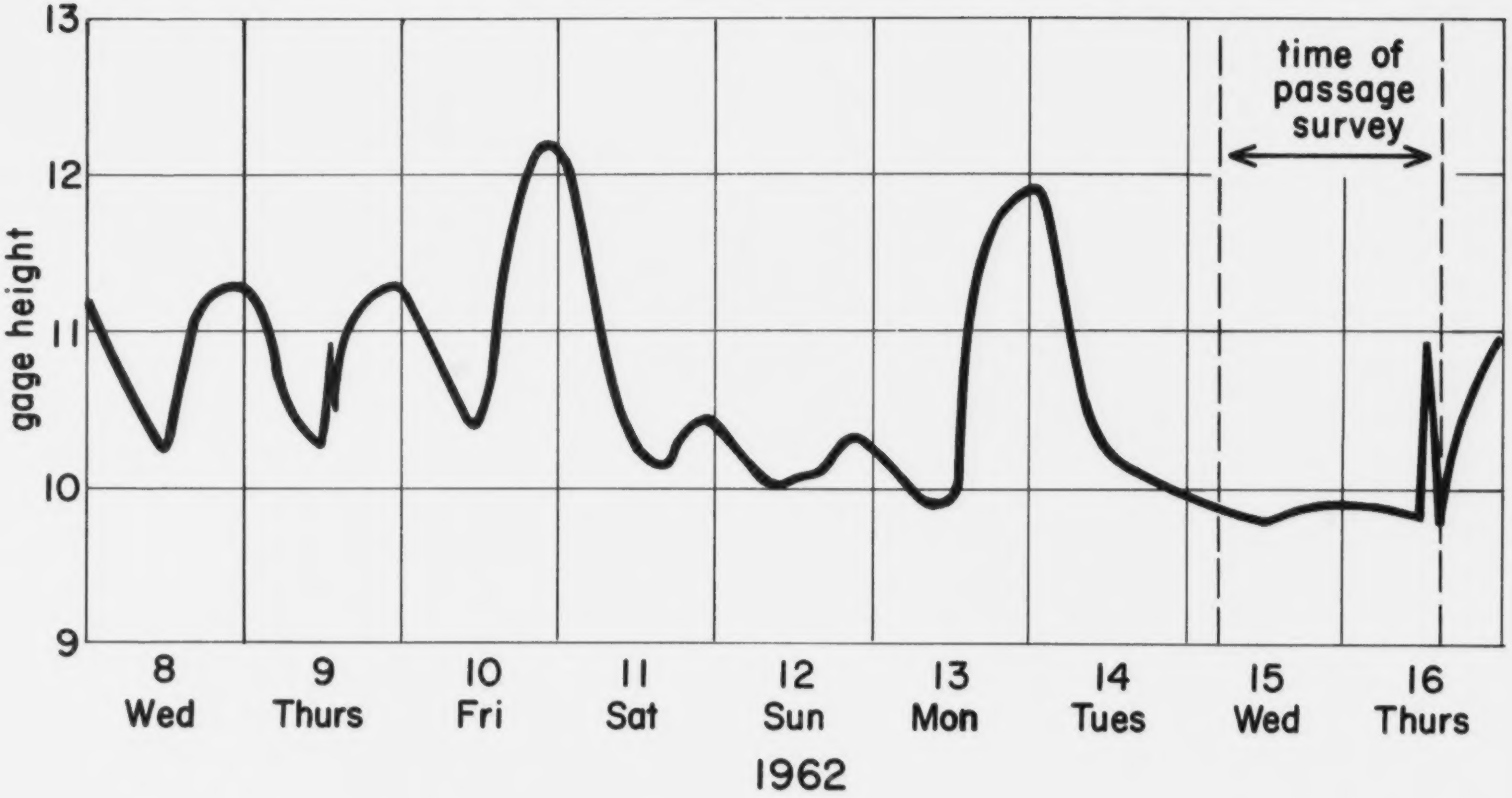


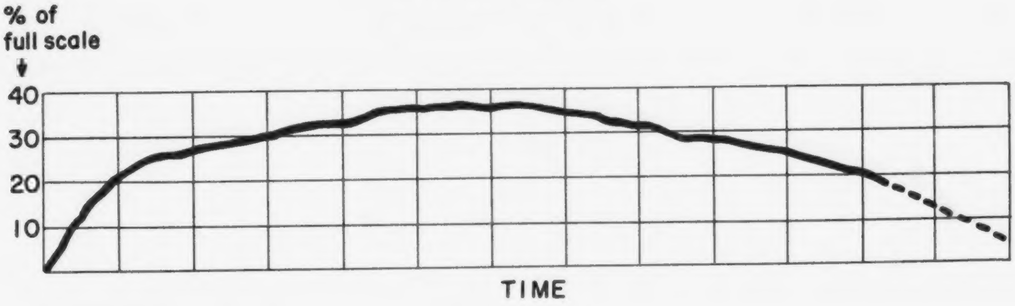
Figure 8-1

It is interesting that a discharge measurement of the Tittabawassee River taken independently by the project personnel at the first convenient sampling station downstream from the diversion amounted to 314.7 cfs, indicating excellent agreement with the sum of the individual upstream measurements. If reliance were placed only on the official U.S.G.S. flow measurement as an indication of downstream flow in the Tittabawassee River during this survey period, the estimates would be in serious error.

Figure 8-2 is a typical fluorometer tracing using Rhodamine B dye detected at Freeland, Michigan on the Tittabawassee River on August 15, 1962. While the dye was introduced as a point discharge at the next upstream station, a distance of 4.23 miles, it is seen that as a result of longitudinal mixing or dispersion it took approximately 3.5 hours to pass the station at Freeland. For a complete discussion of the mixing and diffusion of wastes in streams, the reader is referred to the work of Thomas.(10)

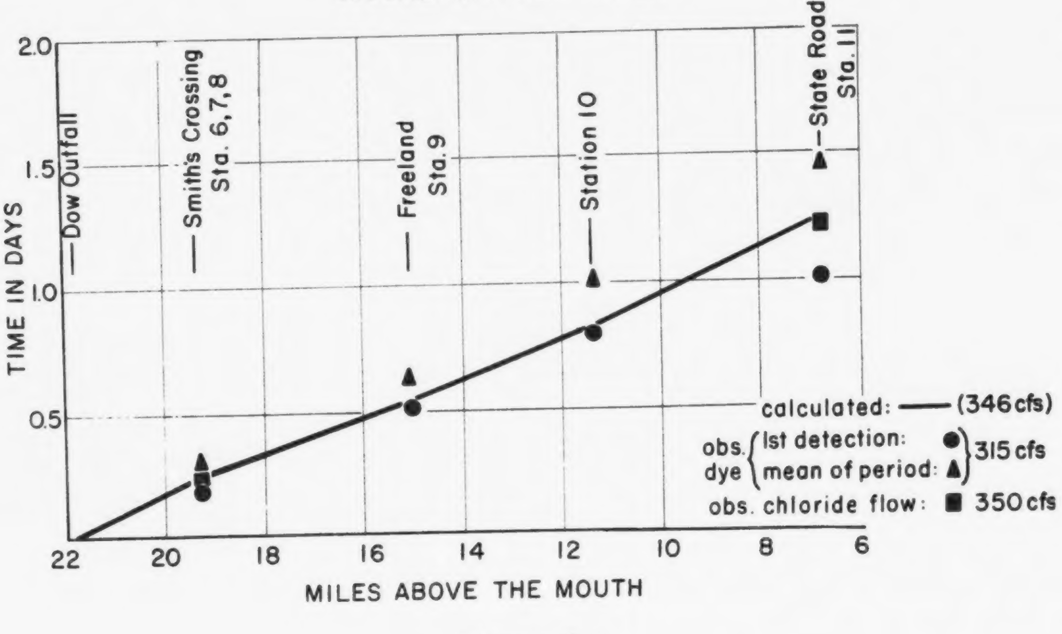
Figure 8-3 is a comparison of the calculated and observed time of passage on the Tittabawassee River for a total river flow below Midland, Michigan in the range of 315 to 350 cfs and, also, includes chloride flow time at a runoff level of 350 cfs. The calculated times were determined on the displacement basis; however, the channel was cross sectioned under higher runoff levels and it was necessary to adjust the volume down to the indicated runoff levels. The observed chloride flow time was reported by the Dow Chemical Company on the basis of chloride concentration studies conducted many years ago, while the dye tracer studies were directed by the writer under controlled river conditions on August 15, 16, 1962.

The results of the Rhodamine B study are plotted in two ways: 1) as the time of first detection which might be important if toxic wastes were involved, and 2) as the mean of the period which should be compared with the displacement calculation. It is seen that reasonable agreement exists to Freeland with greater differences further downstream. The dye studies were conducted at a runoff level of 315 cfs, while the calculated time corresponds to a runoff of 346 which may partially account for the differences. Furthermore, there is a backwater influence at station 11 from Lake Huron, which no doubt contributes to the differences at this station.



TYPICAL FLUOROMETER TRACING
TITTABAWASSEE RIVER
AT
FREELAND, MICHIGAN
AUGUST 15, 1962

Figure 8-2



COMPARISON OF CALCULATED AND OBSERVED
TIME OF PASSAGE
TITTABAWASSEE RIVER

Figure 8-3

Several observations resulting from the dye tracing study conducted on the Tittabawassee River might be mentioned. First, the river velocities determined from time of mean dye flow between stations at 315 cfs were approximately 0.8 ft/sec, with little variation from this figure among the different sections of the river. Also, since the river channel is fairly uniform and shallow, the fluorometer tracings were uniform in distribution and did not show evidence of eddying effects or short circuiting. Although dilution of the dye by the river water had to be taken into account in estimating the concentration of dye to be used in each section of river, there was no evidence of dye loss by adsorption.

SUMMARY AND CONCLUSIONS

Time of passage information assumed particular importance in this project because of specific interest in the river BOD removal rate k_r, which is determined from 5-day BOD samples taken at river sampling stations together with the time of travel between these sampling stations. As a result, efforts were directed toward the determination of adequate time information for both the Clinton River and Tittabawassee River.

Discussion has been presented of the displacement method of calculation, together with a consideration of the use of internal and external tracers. Of the external tracers available, Rhodamine B dye together with a sensitive fluorometer appears to meet most of the needs of a tracer material for inland waters. Such a tracer has been used with success in this project.

Results have been presented of time of passage determinations using the displacement method of calculation for both the Clinton and Tittabawassee Rivers under runoff conditions prevailing during the respective intensive water quality surveys in 1960 and 1961. This information has been used in previous sections of this report. In addition, comparisons have been made for the Tittabawassee River between results obtained using the displacement method with times determined using the external tracer Rhodamine B and an internal chloride tracer. Generally, times were comparable among the methods as far as Freeland, with more divergence further downstream.

The availability of dye such as Rhodamine B together with sensitive fluorometer detection equipment, make an external tracer time of passage study a desirable part of any well planned stream survey. In addition to time evaluation, this technique can be valuable in determining flow velocities, waste mixing and dispersion, vertical, lateral and longitudinal stratification, and short-circuiting or eddying of wastes especially in impoundments.

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SECTION IX

AERATION AT TWO WASTE TREATMENT PLANT OUTFALL STRUCTURES

Aeration through a waste treatment plant outfall structure can be an important asset in terms of river dissolved oxygen levels, particularly if the effluent becomes a significant part of the total river flow below the plant during low flow periods. Two case illustrations are presented where this is the situation--first, the Pontiac, Michigan waste treatment plant discharging its effluent into the Clinton River and, second, the Dow Chemical Company waste treatment plant at Midland, Michigan discharging its effluent into the Tittabawassee River. In both cases routine sampling of the effluent at a convenient point in the plant preceding the outfall unit indicated a relatively low dissolved oxygen concentration, whereas sampling at the point of discharge to the river indicated a considerable oxygen increase. Each case will be illustrated in terms of information collected during special survey conditions, and comparisons will be made between the observed results and predicted results using equations developed recently by British workers studying aeration at weir systems.

BRITISH WEIR RELATIONSHIPS

Investigators at the British Water Pollution Laboratory have reported on studies concerning aeration at weirs both in terms of laboratory and field investigations with the first general report by Gameson,(1) followed by a consideration of the effect of temperature by Gameson, Vandyke, and Ogden.(2) After this, Barrett, Gameson, and Ogden(3) described aeration studies at four weir systems, and more recently, Grindrod(4) gave a general discussion of the subject. As a result of these studies, two general relationships have been proposed--first an expression called the deficit ratio (r) for presenting the change in oxygen content over a weir, and second, an expression for predicting the deficit ratio (r_T) in terms of several factors affecting it. These equations are as follows:

$$r = \frac{C_S - C_A}{C_S - C_B} \qquad (1)$$

where r = deficit ratio
C_S = dissolved oxygen saturation in mg/l
C_A = dissolved oxygen concentration above the weir in mg/l
C_B = dissolved oxygen concentration below the weir in mg/l

and $$r_T = 1 + 0.11\, ab\, (1 + 0.046\, T)\, h \qquad (2)$$

where T = water temperature in °C
h = height in feet through which water falls
a = 1.25 for clean river water; 1.0 for polluted river water; 0.8 for sewage effluents
b = 1.0 for a free weir and 1.3 for step weirs

Thus, it is possible to calculate the observed deficit ratio (r) using equation (1) having water temperature and dissolved oxygen concentration above and below the weir. In addition to this, the deficit ratio (r_T) can be predicted using equation (2) knowing the water temperature (T), the weir height (h), water quality (a), and weir type (b). For the case illustrations to be presented, both relationships will be used and comparisons made between the observed deficit ratios from equation (1) and the predicted deficit rations from equation (2).

CASE ILLUSTRATIONS

Pontiac Waste Treatment Plant

The Pontiac, Michigan, municipal waste treatment plant consists of trickling filter and activated sludge units operating in parallel, with approximately 50 to 60 per cent of the total plant flow going through the activated sludge units and 40 to 50 per cent of the flow going through the trickling filter units as previously presented.

Inconsistencies which developed between river dissolved oxygen values below the plant, and reported dissolved oxygen values of the effluent prompted a special study at several locations in the plant and in the river on July 12, 1961. Of special note was the oxygen increase that resulted from a drop of 3.1 feet over the overflow weir of the chlorine contact tank of the activated sludge system. Figure 9-1 shows both a photograph of the overflow weir and a schematic elevation view of the weir system. On July 12, 1961, during the sampling period the flow through the activated sludge system was reported as ranging between a low of 5 M.G.D. early in the morning to a high of 12 M.G.D. later in the day, while the flow through the trickling filter system was reported as ranging between 2.5 and 8.0, with the total plant flow ranging between 8.0 and 20 M.G.D. The results of several sampling runs starting at 7:47 A.M. and ending at 5:35 P.M. for sampling station 1 above the weir, and sampling station 2 below the weir are summarized in Table 9-1 as follows:

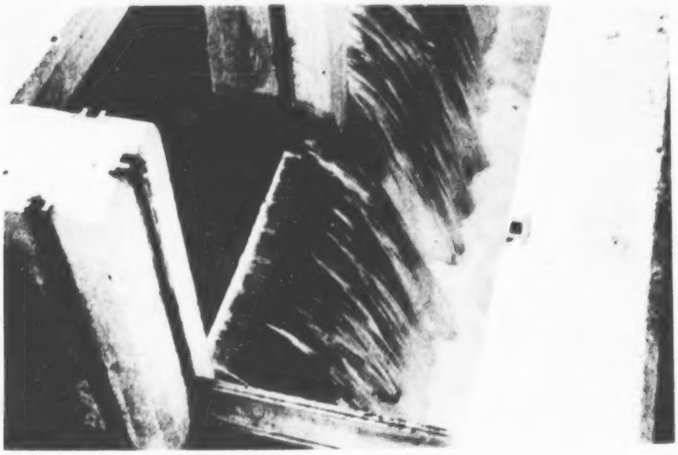
TABLE 9-1

PONTIAC WASTE TREATMENT PLANT SURVEY DATA
July 12, 1961

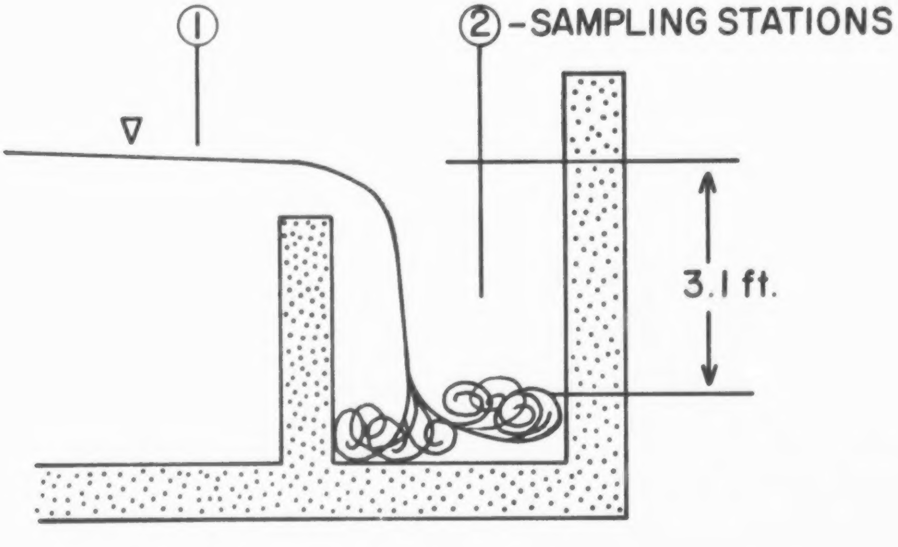
Station 1 (above weir)			Station 2 (below weir)			Deficit Ratio (r)
Time	Temp °C	D.O. in mg/l	Time	Temp °C	D.O. in mg/l	
7:47A	22.0	1.77	7:53A	22.0	5.41	2.06
9:35A	22.0	1.82	9:40A	22.0	5.01	1.84
11:17A	22.0	1.72	11:22A	22.0	4.96	1.84
1:55P	22.5	1.97	1:58P	22.5	5.06	1.84
3:07P	22.5	1.72	3:11P	22.0	4.10	1.51
5:31P	22.5	1.62	5:35P	22.5	3.95	1.49
Average		1.77			4.75	1.73

It is seen that the average dissolved oxygen increase as a result of the drop over this weir amounted to approximately 3.0 mg/l, with the observed deficit ratio (r) averaging 1.73 and individual values ranging from 1.49 to 2.06. Using equation 2, with $a = 1.0$, $b = 1.0$, $h = 3.1$ ft., and $T = 22^{\circ}C$, the deficit ratio (r_T) is calculated as 1.685 which agrees well with the observed mean deficit ratio (r) of 1.73.

WASTE TREATMENT PLANT OVERFLOW WEIR
CHLORINE CONTACT TANK OF ACTIVATED SLUDGE UNIT
PONTIAC, MICHIGAN



a. OVERFLOW WEIR


①
② -SAMPLING STATIONS
3.1 ft.

b. ELEVATIONS ON JULY 12, 1961

Figure 9-1

Looking at this in another way, if the calculated deficit ratio of 1.685 is used with the observed mean dissolved oxygen value of 1.77 mg/l above the weir, the calculated mean dissolved oxygen below the weir using equation (1) would be 4.64 mg/l. This compares quite favorably with the observed mean of 4.75 mg/l and indicates that equations (1) and (2) are applicable in predicting oxygen increase over this weir.

All dissolved oxygen determinations were performed in accordance with the Alsterberg (azide) modification of the Winkler method as described in the 11th Edition of Standard Methods,(5) and were completed shortly after collection at a field laboratory established on the grounds of the Pontiac waste treatment plant. Detailed data for the July 12, 1961 survey is presented in Appendix I-C of this report.

Dow Chemical Company Waste Treatment Plant

The Dow Chemical Company waste treatment facilities at Midland, Michigan consist of a complex of treatment units, including pretreatment of certain wastes, with all wastes finally going through an activated sludge unit before discharge to the Tittabawassee River. As with the Pontiac waste treatment plant and the Clinton River, inconsistencies were noted between dissolved oxygen values observed in the Tittabawassee River below the Dow waste treatment plant outfall, and the reported dissolved oxygen values of the plant effluent. This was especially noticeable during an intensive river survey conducted in August, 1961 when the river flow was low and the waste plant flow became a proportionately larger part of the total river flow.

To investigate and evaluate the oxygen increase through the plant outfall structure, a special survey was conducted on August 1, 1962 by collecting samples at several locations in the plant and in the Tittabawassee River above and below the point of discharge. Figure 9-2 is a diagrammatic sketch of the plant outfall structure indicating the routine sampling stations occupied on August 1, 1962. The key stations from the standpoint of oxygen increase are: station 1 above the weir, station 2 below the weir and a culvert under the road, and station 3 at the bottom of a cascade structure.

WASTE TREATMENT PLANT OUTFALL SURVEY

DOW CHEMICAL COMPANY
AUGUST 1, 1962

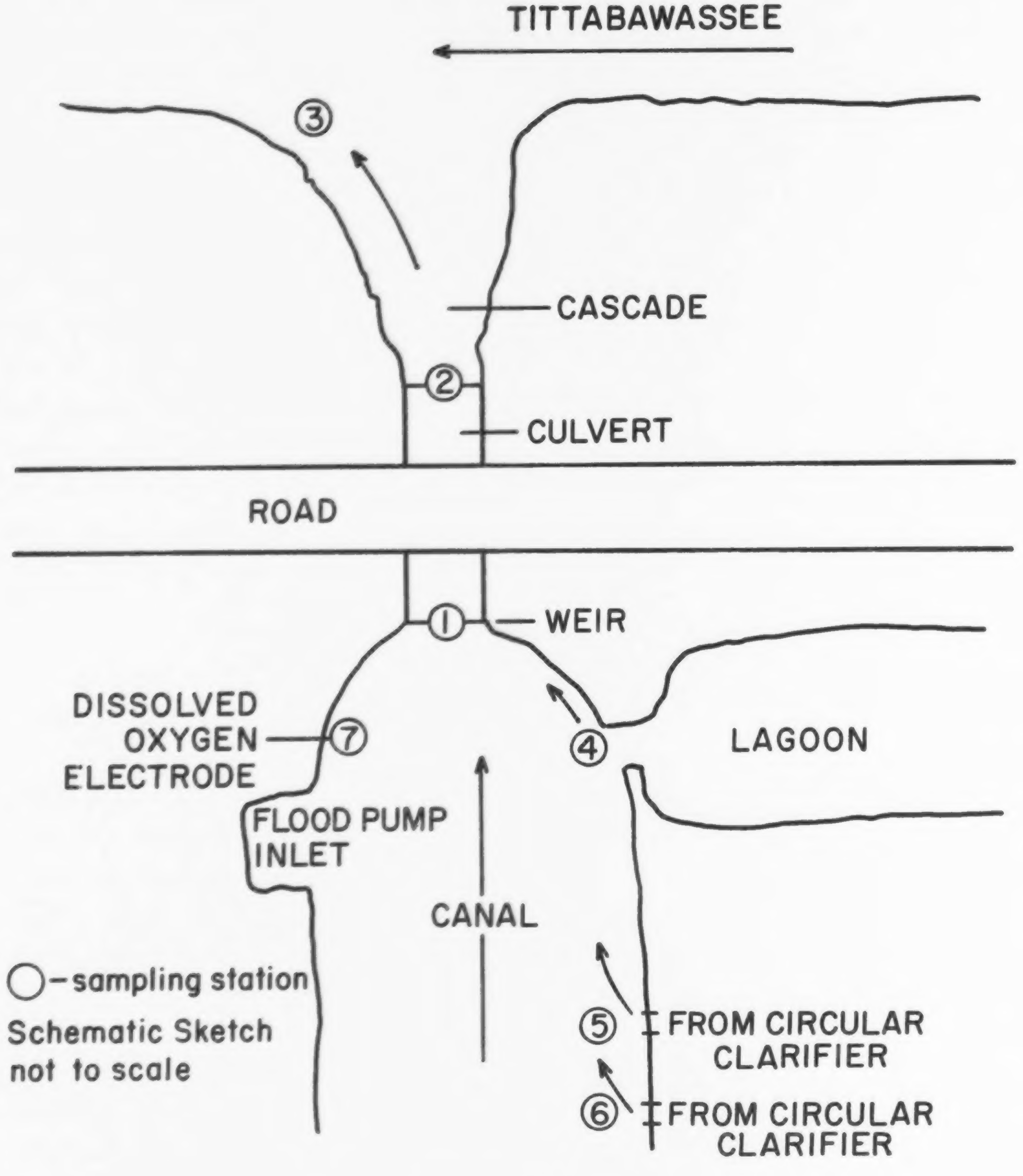

TITTABAWASSEE
③
CASCADE
②
CULVERT
ROAD
①
WEIR
DISSOLVED OXYGEN ELECTRODE
⑦
④
LAGOON
FLOOD PUMP INLET
CANAL
○ – sampling station
Schematic Sketch not to scale
⑤
FROM CIRCULAR CLARIFIER
⑥
FROM CIRCULAR CLARIFIER

Figure 9-2

Three separate runs were made to all of the routine stations starting at 9:26 A.M. and finishing at 6:43 P.M. with the plant flow during this period ranging from 49.57 to 55.14 M.G.D. In addition, a galvanic cell oxygen electrode with continuous recorder as described by Mancy and Westgarth(6) and Mancy, Westgarth, and Okun(7) was installed at station 7, and operated continuously throughout the day indicating very little oxygen change at this station during the sampling period.

The important elevations at sampling stations 1, 2, and 3 on August 1, 1962 are indicated in Figure 9-3(b), while Figure 9-3(a) shows a view of the outfall structure from the Tittabawassee River. Unfortunately, it was not possible because of inaccessibility to establish sampling station 2 any closer to the base of the upper weir, with the result that observed oxygen increases between sampling stations 1 and 2 are caused by aeration at the weir, together with any aeration occurring in the 50-foot partially full culvert.

The basic information collected during this survey is presented in Table 9-2, with the dissolved oxygen analyses performed at the site immediately after collection by the Alsterberg (azide) modification of the Winkler method as described in the 11th Edition of Standard Methods.(5)

TABLE 9-2

WASTE TREATMENT PLANT OUTFALL SURVEY DATA

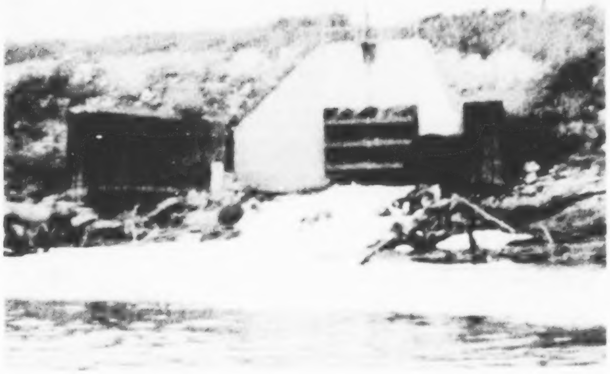
Dow Chemical Company, Midland, Michigan
August 1, 1962

Station	Run 1			Run 2			Run 3		
	Time	Temp.*	D.O.**	Time	Temp.*	D.O.**	Time	Temp.*	D.O.**
1	10:00A	32.0	2.50	2:55P	32.0	1.40	6:23P	32.0	1.70
2	9:50A	31.0	4.70	2:47P	31.0	4.40	6:20P	32.0	4.20
3	10:45A	32.0	5.60	3:17P	33.0	5.10	6:43P	32.0	5.60
4	10:15A	31.5	2.70	3:05P	31.5	12.50	6:28P	32.0	9.30
5	10:20A	32.0	2.50	3:09P	32.0	1.80	6:30P	32.3	1.80
6	10:25A	32.0	3.80	3:13P	32.0	2.00	6:35P	32.3	1.60
7	9:26A	31.1	2.40	2:20P	32.0	2.30	6:10P	32.0	1.70

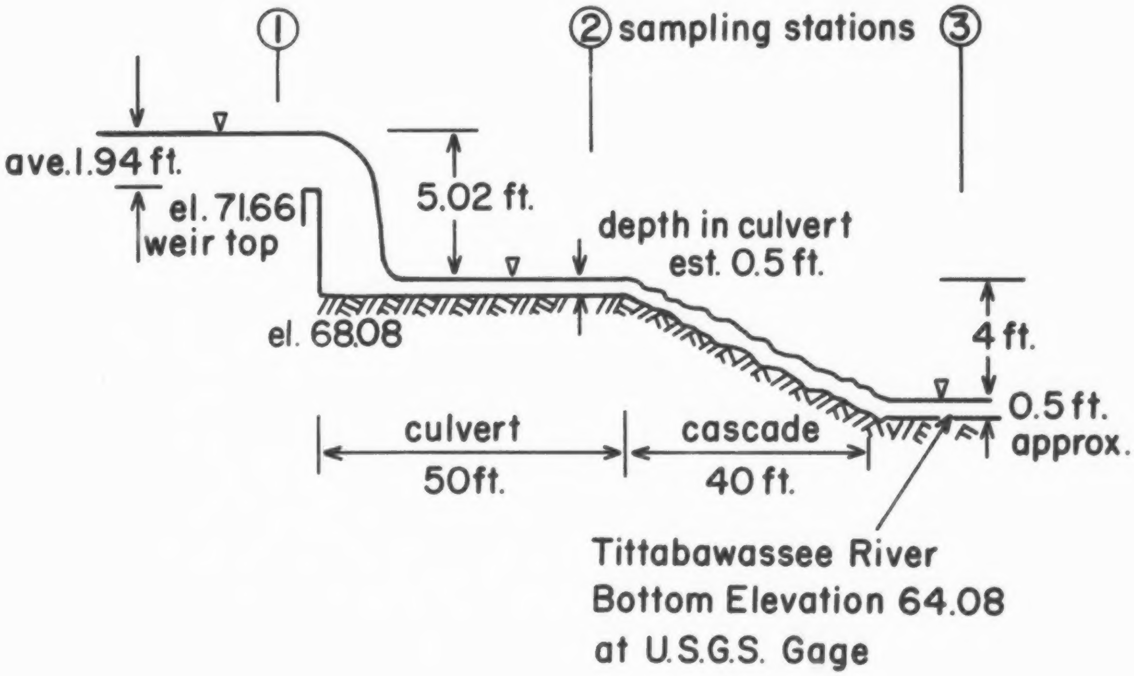
*°C **mg/l

WASTE TREATMENT PLANT OUTFALL STRUCTURE

DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN



a. VIEW FROM TITTABAWASSEE RIVER


①
② sampling stations
③
ave. 1.94 ft.
el. 71.66
weir top
5.02 ft.
depth in culvert
est. 0.5 ft.
el. 68.08
4 ft.
0.5 ft.
approx.
culvert
50ft.
cascade
40 ft.
Tittabawassee River
Bottom Elevation 64.08
at U.S.G.S. Gage

b. ELEVATIONS ON AUGUST 1, 1962

Figure 9-3

The important oxygen relationships for sampling stations 1, 2, and 3 are summarized in Table 9-3 as follows:

TABLE 9-3

OXYGEN CONSIDERATIONS FOR STATIONS 1, 2, 3
August 1, 1962

Run Number	Sta. 1 D.O. mg/l	Sta. 2 D.O. mg/l	Sta. 3 D.O. mg/l	Deficit Ratio(r) Sta. 1 & 2	Deficit Ratio(r) Sta. 2 & 3
1	2.50	4.70	5.60	1.80	1.49
2	1.40	4.40	5.10	1.98	1.30
3	1.70	4.20	5.60	1.78	1.78
Avg.	1.87	4.43	5.43	1.86	1.51

It is seen that the average dissolved oxygen increase between stations 1 and 2 amounted to 2.56 mg/l, with the observed deficit ratio (r) averaging 1.86. Using equations 2, with a = 1.0, b = 1.0, h = 5.02 ft., and T = 32°C, the deficit ratio (r_T) is calculated as 2.36 compared to the observed figure of 1.86. Using 2.36 in equation 1, together with 1.87 mg/l at station 1, the predicted concentration at station 2 is 5.06 mg/l compared to the observed of 4.43 mg/l. Thus, the prediction is approximately 14.2 per cent above the observed.

Considering stations 2 and 3, it is seen that the average dissolved oxygen increase amounted to 1.0 mg/l, with the observed deficit ratio (r) averaging 1.51. Using equation 2, with a = 1.0, b = 1.3 (for step weirs), h = 4.0 ft., and T = 32°C, the deficit ratio (r_T) is calculated as 2.42 compared with the observed of 1.51. With 2.42 in equation 1, and the observed mean dissolved oxygen of 4.43 mg/l at station 2, the predicted concentration at station 3 is 6.17 mg/l compared to the observed of 5.43 mg/l. Thus, the prediction in this case is approximately 13.6 per cent above the observed.

Looking at stations 1 and 3, it is seen that the overall increase consists of 3.56 mg/l. Inasmuch as separate types of weir systems exist between sampling stations, no attempt will be made to combine them for purposes of predicting an overall deficit ratio.

A completely adequate explanation is not available to account for the differences between the observed data and the predicted values using the British weir equations. The question might be raised as to the appropriateness of the constants of equation 2 for this particular physical arrangement, since the oxygen increase between stations 1 and 2 resulted from the combination of weir and culvert aeration, while the increase between stations 2 and 3 resulted from a cascade type of structure rather than a step weir installation. Also, the composition of the waste water and its temperature might have a bearing on the aeration potential, since the waste water is different from any the British investigators worked with and the temperature is above average for most natural streams in the United States and Great Britain.

RIVER BENEFITS

As indicated previously aeration at a treatment plant outfall structure can be an important consideration in the oxygen economy of the river below the point of discharge, particularly if the plant flow becomes an important part of the total river flow. This condition exists in several locations in the United States during drought periods as a result of increased use of river water.

To illustrate this point more specifically, the case of the Dow Chemical Company's discharge to the Tittabawassee River will be cited, and a comparison will be made of the effect on river D.O. between the existing discharge structure and a possible submerged outfall structure for various drought flow conditions. Here, the assumptions will be made that the upstream residual river D.O. concentration above the discharge point is 6.45 mg/l, and that the D.O. of the effluent above and below the existing outfall structure is 1.87 mg/l and 5.43 mg/l respectively, while the plant flow is approximately 75 cfs. Also, it is assumed that no aeration takes place through a submerged outfall and, therefore, the dissolved oxygen of the effluent would be 1.87 mg/l. The important results are summarized in Table 9-4 as follows:

TABLE 9-4

TITTABAWASSEE RIVER

Effect of Outfall Structure on River Dissolved Oxygen Concentration under Various Drought Flows

River Flow		Flow Period	River D.O. Below Outfall			
			Existing Structure		Submerged Outfall	
Above Outfall cfs	Below Outfall cfs		mg/l	% Sat (32°C)	mg/l	% Sat (32°C)
220	296	Aug. 15, 1962	6.19	83.6	5.27	71.2
170	242	1 in 10-year minimum 7-day avg.	6.14	83.0	5.05	68.2
121	197	1 in 10-year minimum daily avg.	6.06	81.9	4.70	63.5
111	185	Lowest observed daily avg.	6.04	81.6	4.60	62.2

For the flow conditions prevailing August 15, 1962, it is seen that the type of outfall structure could make the difference in river dissolved oxygen between 71.2 per cent and 83.6 per cent of saturation, while for the lowest daily average flow of 185 cfs reported in 1949, it could make the difference between 62.2 per cent and 81.6 per cent of saturation. The influence of other drought flows for various durations and return periods as determined by Velz and Gannon(8) is indicated in Table 9-4.

In the United States, two efforts at direct mechanical river aeration by diffused air are reported--one by Wiley et al.(9) for the Flambeau River near Park Falls, Wisconsin, and the other by Palladino(10) for Portage Creek near Kalamazoo, Michigan. Both references indicate a relatively low efficiency, with Palladino reporting an oxygen pickup of 1 mg/l with a power requirement of 1 kw-hr per 0.5 lb. of dissolved oxygen. The Dow outfall structure increased the dissolved oxygen in the effluent in the amount of 1440 lb/day, which would have required 2880 kw-hr if mechanical river aeration were used as reported by Palladino. For a power cost of $.01/kw-hr, it is seen that this would be $28.80/day, exclusive of any capital investment or other operating cost. In addition, none of the mechanical river aeration installations have demonstrated they could increase the river D.O. from 1.87 mg/l to 5.43 mg/l.

Another method of artificial river aeration is by means of turbine venting at power installations. Wiley et al.(11) reports on results accomplished using this technique on Wisconsin rivers which, of course, is appropriate only where a power installation exists. Further evidence of the aerating effect resulting from a drop over a weir or other similar structure such as a dam, is given in a recent study on the Kalamazoo River(12) by the Michigan Water Resources Commission, where it is reported that the river water picked up 2.0 mg/l of D.O. from spilling over the Otsego City Dam.

SUMMARY AND CONCLUSIONS

The significance of aeration at waste treatment plant outfall structures is discussed and illustrated in terms of two case situations--first, the Pontiac, Michigan waste treatment plant discharging its effluent into the Clinton River and, second, the Dow Chemical Company waste treatment plant at Midland, Michigan discharging its effluent into the Tittabawassee River. Comparisons are made between observed and predicted results, using equations developed by British workers studying aeration at weir systems, indicating good agreement in the case of Pontiac, but indicating predictions of the order of 13 to 14 per cent higher than the observed results in the case of Dow.

The river benefits accruing from aeration of this type are discussed and illustrated in terms of a comparison of resulting river D.O. conditions in the Tittabawassee River, under various drought flows, for both the existing type and a submerged type of outfall structure. Also, a discussion is included of possible alternate methods of river aeration such as mechanical aeration using diffused air or possibly turbine venting.

The evidence presented indicates that an open discharge structure is to be preferred over a submerged outfall in terms of improving the oxygen economy of the river. In many installations adequate head is available to accomplish this, particularly during the low flow periods of the year.

ACKNOWLEDGEMENTS

Mr. Jackson R. Pelton and Mr. Joseph Schwerha participated in the field and laboratory studies in the summers of 1961 and 1962.

The cooperation of Mr. John Hennessey, Superintendent of the Pontiac Sewage Treatment Plant, and Mr. John Robertson and Charles Sercu of the Waste Control and Utilization Department, Dow Chemical Co., Midland, Michigan in supplying information and facilitating several phases of this study is gratefully acknowledged.

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SECTION X

PROGRAMMING RIVER DISSOLVED OXYGEN CALCULATIONS

with Thomas D. Downs

The availability of a high speed electronic digital computer such as the IBM 7090 can facilitate the performance of many calculations in the field of stream sanitation, particularly if the operations are of a repetitive nature. A program for the calculation of river dissolved oxygen profiles is discussed employing the methodology of Velz,(1) together with a consideration of the basic data used, program problems encountered, and a case illustration involving the Clinton River in Michigan.

Theory Employed

It is generally recognized that in a river below a source of pollution dissolved oxygen concentration follows what is frequently called the "sag curve", i.e., a fairly rapid drop to a low point with a gradual recovery to a concentration equal to or greater than the original concentration, assuming no new waste source are added. Many years ago Streeter and Phelps(2) proposed a single mathematical expression for this sag curve whereby it is possible to calculate the dissolved oxygen concentration at any point below a source of pollution as a function of time, assuming certain information is available including the waste strength, river flow, initial dissolved oxygen concentration, and a deoxygenation coefficient k_1 and a reaeration coefficient k_2. This relationship combines the basic elements of deoxygenation and reaeration which affect dissolved oxygen levels in a river into a direct solution equation, but depends on a knowledge of the k_1 and k_2 coefficients.

Recognizing that many complex factors are involved in calculation of river dissolved oxygen values, Velz,(1)(3)(4)(5) for many years has advocated the separate evaluation of the deoxygenation and reaeration components with subsequent combination for determination of net oxygen balance. This is the method that has been programmed and which will be illustrated later in this paper.

Generally it is accepted and experience has indicated that the monomolecular reaction as proposed by Phelps(6) best describes the mechanism of river biochemical oxygen demand, but uncertainty exists as to the exact rate of BOD removal in the river. This has been characterized as b by Velz and Gannon(7) where biological extraction is a problem, or as k_r by Eckenfelder and O'Connor(8) to cover any situation where the river removal rate is greater than the laboratory dexoygenation rate k_1. Notwithstanding this lack of ability to predict in advance what the b or k_r will be without specific water quality river information, it can be defined from observed river BOD information, and once defined tends to stay constant for a given stretch of river except for temperature correction as proposed by Velz and Gannon(7) for biological extraction, or as proposed by Velz(4) for sludge deposits. Therefore, with adequate observed river BOD and time of passage information, it is possible to define river BOD removal rates which can be used in the computer program. If, however, this detailed information is not available, it is a simple matter to computer calculate the effect of a range of river BOD removal rates on the resulting dissolved oxygen profile. Thus, from a knowledge of the river BOD removal rate together with information on the period of accumulation if sludge deposits or biological extraction is involved, and assuming the monomolecular reaction applies, it is possible to program this phase of the calculation.

Dissolved oxygen is or becomes available in a river to meet the needs of decomposing organic material from two main sources, (1) the oxygen dissolved in the river water above the waste source and in the waste source itself, together with new tributary dilution water, and, (2) oxygen which dissolves in the water as a result of reoxygenation from the atmosphere. Quantitative evaluation of the oxygen available from the first source, i.e., upstream river water, the waste source, and tributary water, involves knowledge of the runoff in each case, together with the oxygen concentration. Quantitative evaluation of oxygen obtained from the second source, i.e., reoxygenation from the atmosphere, is a much more complicated task but can be accomplished with reasonable accuracy. In some cases oxygen produced as a result of the photosynthetic activity of aquatic plants and algae may be important in checking observed field survey information, but usually this is not a reliable source of oxygen and generally is not considered in predicting dissolved oxygen conditions.

One of the first fundamental approaches to the evaluation of reoxygenation was made by Black and Phelps(9) when they stated that reoxygenation was governed by two fundamental laws, (1) the law of solution and (2) the law of hydro-diffusion. The rate of reoxygenation is inversely proportional to the amount of dissolved oxygen present, i.e., the less oxygen present, the greater the rate of reoxygenation up to a maximum rate when no oxygen is present. Basically the relationship proposed by Phelps, sometimes called Fick's Law of Hydro-diffusion, is for diffusion in quiescent water which must be translated into a flowing stream by means of a mix concept.

From these laws, the mathematical relationship proposed by Phelps and put into a graphical form by Velz is:

$$D = 100 - \left[(1 - \frac{B}{100}) \times 81.06 \left(e^{-K} + \frac{e^{-9K}}{9} + \frac{e^{-25K}}{25} + \ldots\right)\right]$$

where D = final D.O. content (average for the depth) as % of saturation/mix

B = initial average D.O. content as % of saturation

$K = \frac{\pi^2 at}{4L^2}$ (This is not the same k_1 or k_r used in deoxygenation relationships.)

in which

t = time of exposure in hours

L = depth of water in centimeters

a = diffusion coefficient for specific temperature (determined experimentally)

Velz solved the above equation assuming the initial dissolved oxygen concentration (B) = 0 and expressed it in graphical form as illustrated in Figure 10-1. It should be recognized that this is a refinement of the original curve published in 1939(1) with Figure 10-1 in its present form first appearing in Sewage Works Journal in 1947.(3) It can be seen from the basic

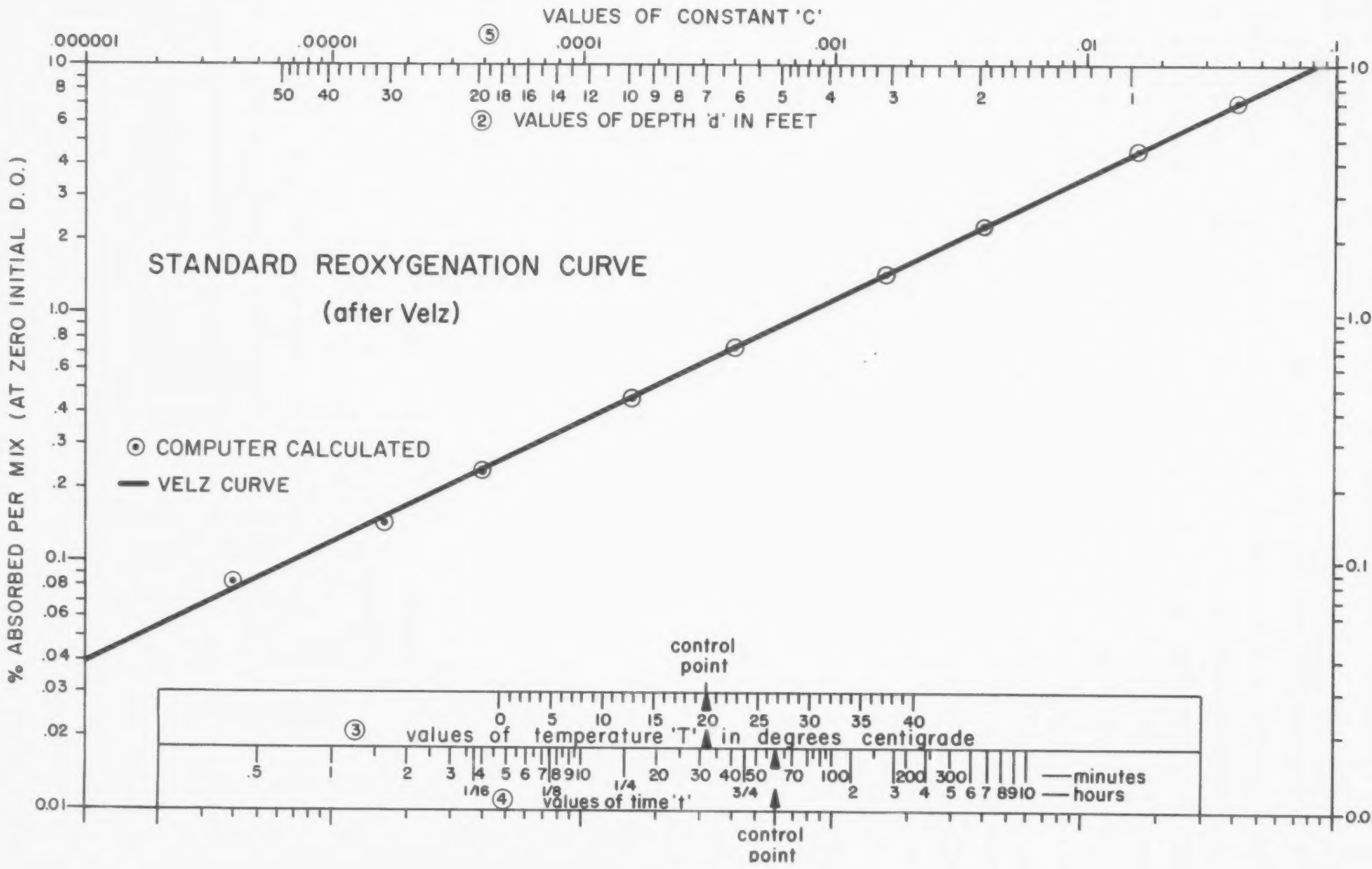
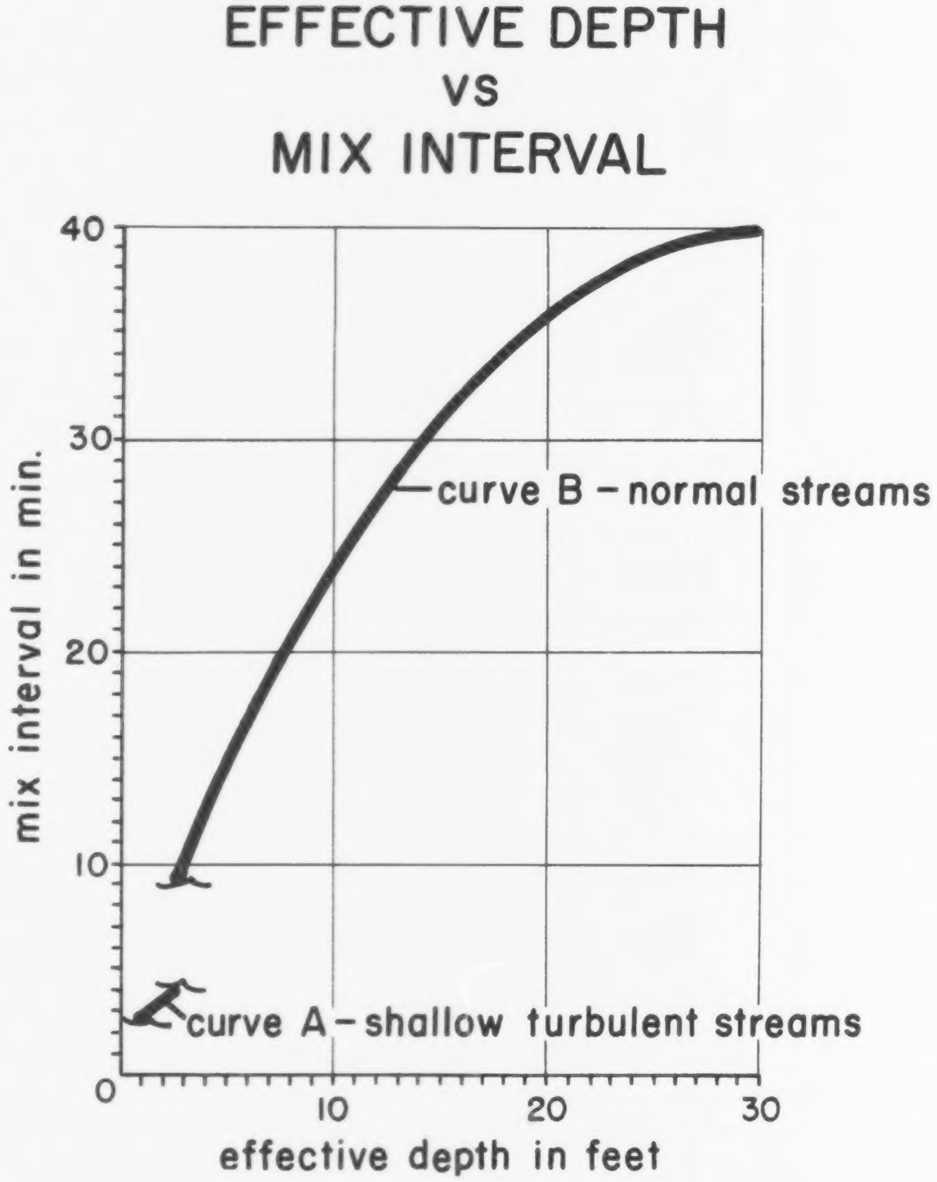

VALUES OF CONSTANT 'C'
⑤
.000001
.00001
.0001
.001
.01
.1
50 40 30 20 18 16 14 12 10 9 8 7 6 5 4 3 2 1
② VALUES OF DEPTH 'd' IN FEET
% ABSORBED PER MIX (AT ZERO INITIAL D.O.)
10
8
6
4
3
2
1.0
.8
.6
.4
.3
.2
0.1
.08
.06
.04
.03
.02
0.01
STANDARD REOXYGENATION CURVE
(after Velz)
⊙ COMPUTER CALCULATED
— VELZ CURVE
control point
0 5 10 15 20 25 30 35 40
③ values of temperature 'T' in degrees centigrade
.5 1 2 3 4 5 6 7 8 9 10 20 30 40 50 70 100 200 300
—minutes
1/16 1/8 1/4 3/4 2 3 4 5 6 7 8 9 10
—hours
④ values of time 't'
control point

Figure 10-1

equation that expansion of a series is involved, which originally was both tedious and time consuming taking into account in some instances hundreds of terms. As part of this programming procedure, the basic calculations were checked by computer technique with the computer results indicated in Figure 10-1. Thus, the original calculations were verified with computer expansion of nine points involving 2000 terms in a matter of 11.4 seconds of computer time.

Inspection of Figure 10-1 indicates that it is necessary to know the mean channel depth, d (scale 2), the stream temperature, T (scale 3), and a time of mix value, t (scale 4), in order to determine the per cent of oxygen saturation absorbed per mix at zero initial dissolved oxygen. For oxygen concentrations other than zero, this figure is related on a linear basis to the dissolved oxygen deficit, e.g., at 60 per cent dissolved oxygen concentration the deficit would be 40 per cent and, therefore, the rate of reoxygenation would be 40 per cent of the maximum rate for 100 per cent deficit. In addition, for a quantitative evaluation of the amount of oxygen obtained from reaeration in terms of lbs. per day, it would be necessary to know the appropriate volume of river water which could be calculated from river channel information.

Of the factors entering into the reoxygenation calculations, the one most difficult to evaluate has been the time of mix. Originally it was related by Velz(1) to velocity and depth based on limited experimental channel data, but this proved inadequate for full scale river situations. It became necessary to resort to an indirect semi-empirical approach to establish a relationship between mix interval and effective depth as illustrated in Figure 10-2, based on a number of different river situations. Also, it has been necessary to make a distinction between shallow turbulent streams with effective depths less than 3 feet indicated as Curve A, and deeper rivers indicated as Curve B. For programming purposes, a six-degree polynomial was fitted to Curve B and a linear relationship was used for Curve A.



EFFECTIVE DEPTH
VS
MIX INTERVAL

Figure 10-2

BASIC INFORMATION

For the calculation of a dissolved oxygen profile employing separate evaluation of stream deoxygenation and reoxygenation characteristics as proposed by Velz, several important types of information are necessary including physical characteristics of the river channel, river runoff, time of passage, pollution loads, river oxygen removal and utilization rates, and river water temperatures.

Channel Characteristics

As a basis for calculation of time of passage and, also, reaeration, it is necessary to adequately define the river channel characteristics. In some cases this information may be readily available from another source such as the files of the Corps of Engineers covering flood protection or navigation studies, or, it may be necessary to collect the information in the field. If this is the case, adequate definition of channel characteristics for the purpose at hand can generally be obtained by cross sectioning the relevant river stretches at about 500-foot intervals. This need not be done with a high degree of surveying accuracy, but rather, emphasis should be placed on more frequent sounding wherever possible. Physically it can be accomplished by means of a tape and sounding rod or weighted line, together with a good map of the river stretch in question for location and orientation in the field. Figure 10-3 shows a typical river cross section on the Clinton River in Michigan measured in this manner.

For purposes of programming, the calculation of cross sectional areas can be facilitated by breaking the section into a series of triangles and trapezoids, and then summing these individual areas for determination of the section area. Also, the occupied channel volume between sections can be calculated using the average end area method.

Since river cross section work may extend over several days, with the possibility of varying runoff during the period, it frequently is necessary to adjust river stage to a common runoff regime. Here a rating curve such as illustrated in Figure 4 is necessary, and ideally should be available for every cross section. Unfortunately, this is rarely the case and in most instances

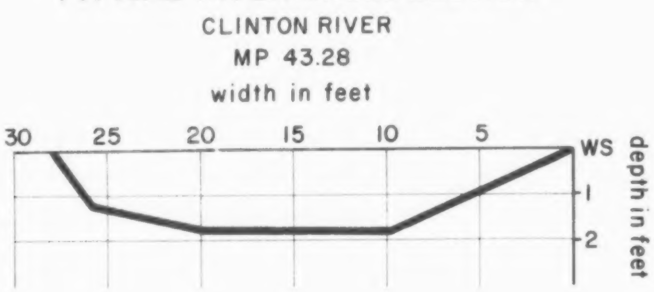


Figure 10-3

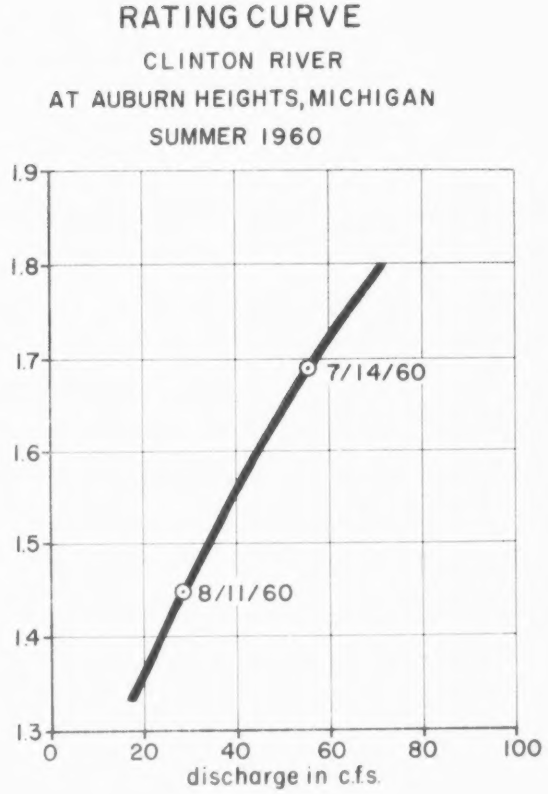


Figure 10-4

reliance must be placed on some nearby gage assuming the channel characteristics at the gage are representative of the river stretch in question. In addition to adjusting individual cross sections to a common runoff regime, this technique is equally applicable in adjusting river volumes from one runoff level to another. For example, if the river is cross sectioned at a runoff of 60 cfs and it is necessary to have an estimate of river volume at 30 cfs, the gage height decrease for this change in runoff can be used as a basis for volume adjustment.

Where extensive cross section work is necessary, field work can be facilitated by means of a portable recording fathometer(10) which gives a continuous record of channel depth. The cost of an instrument of this type can be recovered in a short period of time in terms of reduced labor costs, and in addition, will provide more information than can be provided using the more conventional methods.

River Runoff

River runoff affects the self-purification capacity of a stream both in terms of its effect on time of passage and, also, because of the dissolved oxygen present in the runoff before pollution is introduced. Generally speaking, the more runoff, the greater is the capacity of a stream to assimilate waste. Where a pollution problem exists and an effort is made to independently check a river water quality survey, it is necessary to know the runoff that prevailed during the river survey; in this case, the runoff must be measured either at an existing stream gaging station or, if this is not possible, discharge measurements must be taken at the time of the water course sampling.

In addition to runoff information at a given point on a river, it usually is necessary to know the runoff at various locations through a critical stretch. Here, knowledge of the relationship between drainage area and river location is helpful in estimating runoff at these several locations where it is possible to increase runoff in proportion to an increase in drainage area. A typical relationship of drainage area to river distance developed from topographic considerations is illustrated as Figure 10-5 for the Clinton River from Pontiac to Rochester. Obviously this approach is applicable only to stretches of river that have reasonably uniform drainage area characteristics, and should not be used where tributaries with different yield characteristics enter the section in question.

For proposed pollution loadings, in contrast to existing pollution loads, it frequently is necessary to evaluate the effect of runoff on the stream capacity, and here it is desirable to know the probability of various low flows. Recently a statistical study of the drought characteristics of the streams of the State of Michigan was completed by Velz and Gannon(11) which serves as a basis for relating water quality during a specific low runoff period to a probability of occurrence. Similar studies could be made on records from one or more stream gaging stations in other basins.

Time of Passage

For the evaluation of the deoxygenation component of the oxygen balance relationship a knowledge of the river time of passage is necessary. The basic BOD reaction is a time-temperature relationship and, therefore, the river time of passage, rather than the river distance, is the parameter needed.

Calculation of the time of passage can be accomplished on a displacement basis from a knowledge of the runoff together with the corresponding river volume. This is the method that has been programmed for computer calculation, and presumes knowledge of the river channel characteristics and runoff to the degree previously discussed. Also, times for other runoff levels can be calculated by adjusting volumes using an appropriate rating curve.

Recently the opportunity existed on a Michigan river to check the calculated time by means of an external dye tracer technique, with excellent agreement between the two approaches. However, it should be recognized that modifications in the calculated approach may be necessary, particularly where there are widely varying channel characteristics, or where pool areas may exist created by dams resulting in little change in river stage over fairly wide ranges of runoff.

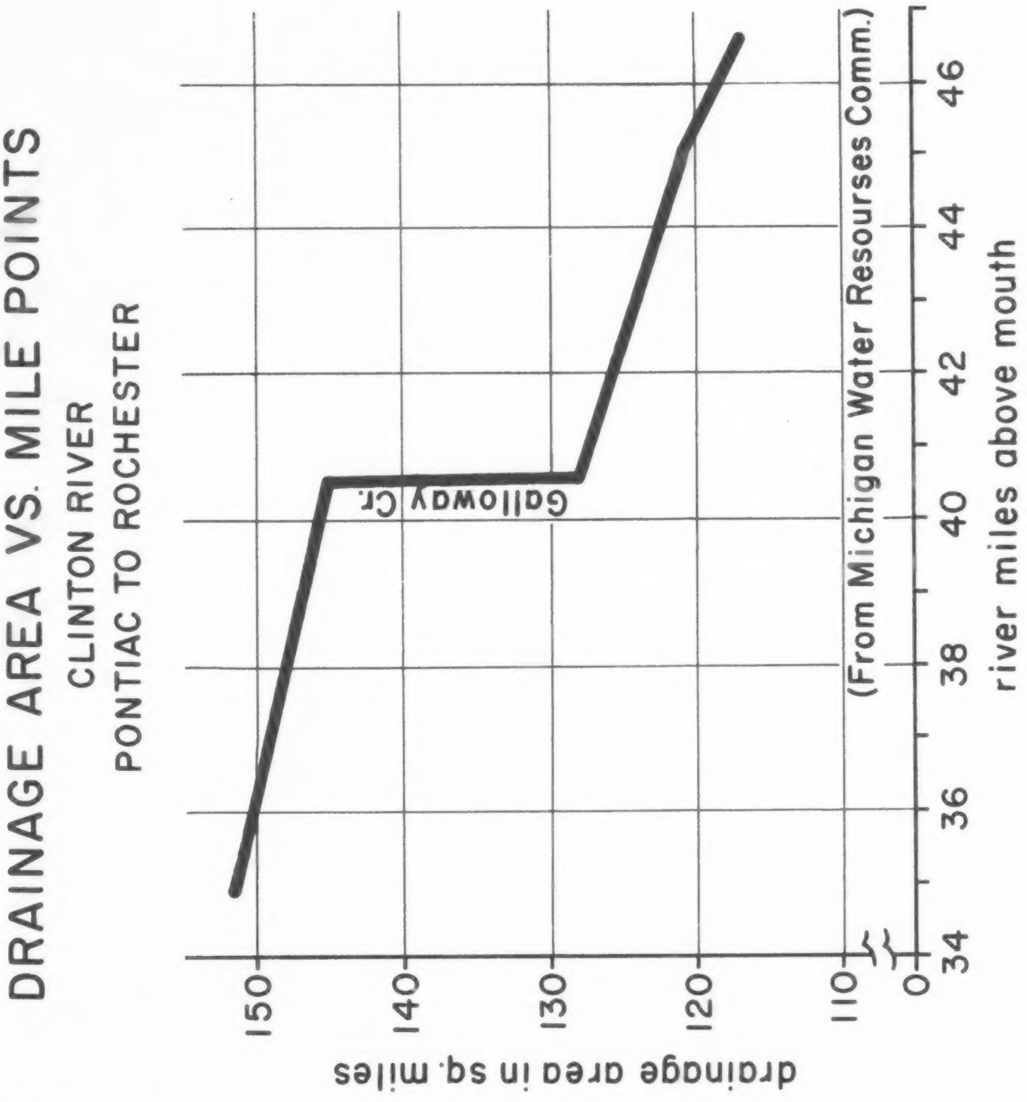

DRAINAGE AREA VS. MILE POINTS
CLINTON RIVER
PONTIAC TO ROCHESTER
drainage area in sq. miles
150
140
130
120
110
0
34
36
38
40
42
44
46
river miles above mouth
Galloway Cr.
(From Michigan Water Resourses Comm.)

Figure 10-5

In a recent paper, O'Connor(12) developed a relationship centered around the oxygen sag curve which did not require knowledge of time of passage, but instead needed information on distance and average depth of stream between stations. No doubt this is a simplification of calculation and a saving in some field effort, but in so doing certain generalities must be employed which detract from the accuracy which can be obtained.

Pollution Loads

Specific information on pollution loads is necessary, and these loads should be determined from measurements at the source rather than indirectly from river water quality determinations. Sampling should be conducted over a representative time period to reflect hour to hour or day to day fluctuations in the case of a municipal source, or to reflect normal production conditions in the case of an industrial source. Normally the organic waste load is expressed in terms of its biochemical oxygen demand (BOD), and involves knowledge of the BOD concentration measured in terms of five-day BOD in the laboratory, together with the corresponding flow rate measured at the source. Combining the concentration and the flow, it is possible to arrive at an absolute figure of lbs/day of five-day BOD which can be converted to ultimate BOD from a knowledge of the laboratory k_1 rate. If this laboratory rate is not known, it may be necessary to conduct separate laboratory rate studies using either the conventional dilution technique, or the reaeration technique as proposed by Elmore.(13) Also, it is desirable frequently to express organic waste load in terms of population equivalents, rather than lbs/day, especially if an industrial waste source is involved. The conversion figure of 0.24 lbs/day of ultimate BOD per person has been used successfully.

Another factor which should be evaluated in the laboratory is the presence or absence of an immediate demand. If such a demand exists, it can be handled, and provision for such a situation has been included in this program. Also, the presence of BOD in the settleable form should be determined in the laboratory, particularly, if the river water velocity is such as to allow deposition of solids.

For purposes of this computer program, the basic input is pollution load expressed in population equivalents.

River BOD Removal Rate

As discussed previously, knowledge of the river BOD removal rate is important and usually cannot be predicted quantitatively if abnormalities such as biological extraction and accumulation are involved. Where possible, this removal rate should be evaluated in the field from representative BOD samples collected through the critical stretch, together with a knowledge of the time of passage involved. Such an evaluation has been previously illustrated in this report for the Clinton River in Michigan, where BOD information was collected every four hours around the clock, for a 48-hour sampling period through the critical stretch. Here, it is to be noted, the overall BOD removal expressed as k_r is equal to 1.1, for an average river water temperature of 20^oC. The river is shallow and turbulent through this stretch, with many types of attached aquatic weeds involved, which behave much as the stones in a trickling filter in extracting organic matter.

Not all rivers have high BOD removals, and many have rates which closely parallel the rates determined in the laboratory bottle experiments. This appears to be particularly true for the larger rivers, where there is relatively less contact with the river bottom and sides, and where there is no gross dispersed type of growth.

For this phase of the computer program, the basic input is the river BOD removal rates expressed as k_r.

River Water Temperature

Water temperature plays an important role in both the deoxygenation and reaeration phases of oxygen balance calculations and, therefore, in all river survey work should be a component of the physical measurement taken. Generally this information is available in the case of existing water quality data, but is lacking where predictions are needed, particularly if a heat load is associated with an organic load.

Methods for forecasting heat loss in streams, and, also, for calculating equilibrium water temperatures under natural conditions from a knowledge of certain meteorological conditions, have been available as presented by Velz and Gannon,(14) but the calculations have been tedious and time consuming. Both heat loss calculations and equilibrium water temperature calculations have been programmed, and can either be handled separately or incorporated as part of the dissolved oxygen calculations. It is beyond the scope of this paper to consider further the details of heat loss programming.

PROGRAMMING CONSIDERATIONS

All of the basic information previously discussed is necessary as computer input and, being in a numerical form, can be entered directly onto punched cards. This, then, is the first step in the computer operation and is, no doubt, the most time consuming part of the procedure. Also, since there is the possibility of human error in punching, repeat punching for verification purposes is generally required.

Several problems were encountered in attempting to write the computer program. For instance, the nomograph of Figure 1 had to be expressed in analytical form: a form which the computer could understand. As previously mentioned, this involved evaluation of the infinite series:

$$\frac{e^{-K}}{1} + \frac{e^{-9K}}{9} + \frac{e^{-25K}}{25} + \ldots$$

The series was expanded by the computer for each of nine values of K with the computer receiving instructions to continue adding terms for each summation until the terms became smaller than 10^{-8}. From this information a curve was developed relating the sum to the corresponding value of K, thus, converting the nomograph to a form suitable for computer use.

In addition to this problem, several tables had to be expressed in equation form rather than directly entering the tabular value onto punched cards, since a relatively large amount of time is required by the computer to "search" extensive tables. For these tables, a program was written which would fit a polynomial of arbitrary degree, by the method of least squares, to a collection of points. If the degree of the fitted polynomial is not too large, the computer can quickly calculate the values, thereby realizing a saving in computer time.

Throughout the planning and writing of the program every effort was made to preserve generality, so that oxygen profiles could be computer calculated for all types of rivers. Given the basic information, any number of hypothetical situations can be evaluated in a very short period of time.

As developed in this program, the output information would consist of the river mile point expressed generally in miles above the mouth, together with the corresponding dissolved oxygen value expressed in per cent of saturation. For the calculation of each individual dissolved oxygen value, the computer performs about 100 multiplications or additions, and makes about 20 logical decisions.

The program was written in the MAD language,(15) a computer language developed at The University of Michigan. Since the techniques used in this language are generally available in most electronic computers, a program patterned after the MAD program could be developed for other computers.

CASE ILLUSTRATION

For purposes of verifying the program, a case situation was selected where all of the necessary information was available involving the Clinton River in Michigan between Pontiac and Rochester. Since the method of calculation does not use the observed river dissolved oxygen data, this information is reserved for checking the calculated values.

Clinton River, Michigan

The section of this river under consideration is located in the headwaters of the basin below the city of Pontiac, and above the city of Rochester as previously discussed. Total flow in the river below Pontiac during the survey period was approximately 33 cfs, with more than half of this flow composed of the effluent from Pontiac waste treatment plant, which is the major waste source in this section of the river. It is interesting that this plant consists of trickling filter and activated sludge units in parallel, so that part of the waste goes through one system and part through another system. Information is available on the pollution load during the survey period from both parts of the plant effluent, based on BOD analyses made by the plant personnel.

As far as the river itself is concerned, it is shallow with mean depths ranging from 1.0 to 2.0 feet, with turbulent stretches interspersed with shallow pool sections. Profuse growths of aquatic weeds were observed in several locations through the critical section.

Fortunately, as indicated previously, adequate basic information is available on this river including channel cross-sections at 500-foot intervals, river runoff measured by a continuous recording U.S.G.S. stream gage located in the critical reach, and river water temperature, together with representative water quality information consisting of BOD and D.O. analyses collected every 4 hours over a 48-hour sampling period.

Employing the program previously discussed, a dissolved oxygen profile was computer calculated for the August, 1960 survey conditions using a river $k_r = 1.1$ and laboratory $k_1 = 0.1$, indicating excellent agreement between the computed and observed river dissolved oxygen data as presented in the Clinton River section of this report.

For purposes of checking the computer results, the dissolved oxygen profile was calculated a second time using traditional methods involving certain graphical and desk calculator operations. Table 10-1 shows a comparison of the computer results and the more conventional methods, indicating good agreement between the two.

Inasmuch as the computer approach does not involve personal judgment, it no doubt is more consistent than the conventional methods employing graphical procedures.

It is interesting that the computer time necessary to calculate this profile on an IBM 7090 was less than 11 seconds at a cost of approximately $1.00. Normally using the conventional

TABLE 10-1

CLINTON RIVER

Comparison of Dissolved Oxygen Profiles
Using Different Methods of Calculation

River Mile Point	Dissolved Oxygen in % of Saturation	
	Conventional	Computer
45.74	81.3	81.3
45.08	62.1	61.05
44.87	53.4	53.37
44.32	41.5	41.27
43.75	29.7	29.93
43.37	25.6	25.35
42.99	26.8	26.29
41.95	22.7	21.67
40.61	32.5	32.28
39.78	37.0	36.61
38.15	50.3	49.58
36.27	61.4	60.45
34.98	66.3	64.98

methods, it would take a technically trained person approximately one to one and one-half days to perform the same calculations.

A detailed explanation of the oxygen profile program is presented as Appendix IV of this report.

SUMMARY AND CONCLUSIONS

A method for programming river dissolved oxygen calculations is discussed employing the approach proposed by Velz. Several illustrations of the types of basic information needed are given, employing data collected on the Clinton River in Michigan. In addition, there is a discussion of the program considerations, together with a case illustration involving the Clinton River in Michigan. Time and cost figures are given for the Clinton River calculations, indicating considerable savings in technical labor and, no doubt, increasing the reliability of the results because of reduction in the possibility of human error.

While the program discussed in this report will facilitate river dissolved oxygen calculations, it covers only part of the evaluation of river self-purification capacity. Certainly, the collection of the required field information is both time consuming and costly, but is necessary for accurate computer calculation and cannot be eliminated.

One main advantage of the use of high speed computers will be the possibility of evaluation of a number of hypothetical situations including the effect of a wide range of pollution loads and, also, a wide range of runoff conditions, which is important in making decisions as to future courses of action, either in terms of an existing pollution problem or in terms of a potential problem.

ACKNOWLEDGEMENTS

The facilities of The University of Michigan Computing Center were utilized at no cost to this project. Mr. Downs participated in this study while recipient of a U.S.P.H.S. traineeship in biostatistics.

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SECTION XI

RIVER BIOLOGICAL SURVEYS

with

Jackson R. Pelton

To supplement the chemical and biochemical data collected during this study, several biological surveys were conducted both on the Clinton and Tittabawassee Rivers. Because it was felt that the high river BOD removal rates might be due to either sludge deposits or biological extraction and accumulation, special attention was given to the collection of evidence which could prove or disprove this assumption.

This section of the report will describe the procedures followed in the river biological survey phase of the study, and will also include a discussion of the results of biological data collected on both the Clinton and Tittabawassee Rivers.

Procedures

Field Procedures

During the period 1960-1962 several field trips were made to each of the rivers for the purpose of visual observation of conditions in the critical section of the river. In some cases this was done by boat, while in others it consisted of wading the river at accessible locations or of making observations from river banks or bridges. These trips were extremely valuable in giving the investigators a "feel" for the respective rivers, thus, allowing the human element to supplement the many physical, chemical and biological measurements.

For purposes of comparison, field trips were also made to the Paw Paw and Kalamazoo Rivers in Michigan, where the phenomenon of biological extraction and accumulation was known to be present. These trips included limited biological sampling.

During the summer and fall of 1961 and again during the spring and summer of 1962, several biological sampling runs were made to the Clinton and Tittabawassee Rivers, and included the collection of both plankton and bottom samples. Plankton samples generally were collected by a No. 20 mesh plankton towing net used either from a boat, by wading or from a bridge. For purposes of standardization, all collections were made by allowing the water to flow through the net for a one-minute time interval. In addition to the use of the net, plankton evaluations were also made on 2-liter samples collected from the river, or on 5-gallon samples brought into the laboratory for BOD rate analysis. On occasion where any larger floating material was observed, it was collected directly into a container or by means of a sieve.

In shallow water locations, bottom samples were collected directly by hand or by use of a Surber type bottom sampler, whereas in deeper water the Ekman dredge was generally used. Collection of material in the littoral zone of the river, and of attached types of growths on stones, tree limbs, etc. was done by hand. Also, as previously mentioned in this report, six-inch square quarry tiles were placed in wooden racks constructed in the river at Auburn Heights on the Clinton River and Smith's Crossing on the Tittabawassee River. These tiles were removed periodically during the summer and fall of 1961, and brought back to the laboratory for microscopic evaluation of the scrapings.

Laboratory Procedures

Of the samples collected for microscopic evaluation, some could be examined directly, while others had to be concentrated. When this was necessary, it generally was done by centrifuging 50 ml of river water in a conical centrifuge tube for 15 minutes at 1500 rpm, and then using a 1 ml residue left after decanting the supernatant fluid. Portions of this material were examined microscopically. Another method of concentration involved passing 25 ml of river water through a 25 mm membrane filter.

Biological evaluation of the samples consisted in some cases of visual inspection for detection of the large forms present or for gross evidence of slime flocs, sludge fragments, clumps of algal growth, etc. while in other cases samples were examined with a variable powered stereomicroscope for detection of the larger types of microorganisms. Final examination and identification was performed using a phase contrast microscope.

For the most part, standard references were used as aids in the identification of organisms present, including Standard Methods,(1) together with the works of the following authors or editors: Edmondson,(2) Palmer,(3) Whipple et al.,(4) Smith,(5) Needham et al.,(6) and Breed et al.(7)

Discussion of Biological Results

Clinton River

During the summer and fall of 1961 and the spring of 1962, periodic field trips were made to the Clinton River for river observation and collection of biological samples for laboratory examination. These samples were collected from the river in the vicinity of plant bridge (M.P. 46.50), just upstream from the Pontiac waste treatment plant outfall, from the activated sludge and trickling filter effluents, from approximately fifty yards below the outfall, and from the river in the vicinity of all of the sampling stations downstream to Yates Mill (M.P. 31.69). A total of 70 samples of various types were collected and examined during this period. No attempt will be made to present here the detailed data of all of the biological findings, but a summary and discussion of the general evaluation of the biological aspects of the Clinton River will be presented.

Results of biological samples revealed that the Clinton River possessed a great variety in both species and numbers of organisms normally expected in a productive river having all of the proper conditions conducive to abundant biological growth, i.e., a high organic nutrient content, varying dissolved oxygen concentrations, and compatible pH and water temperatures. Repeated field surveys failed to show evidence of either sludge deposition zones or observable heavy biological growths. Upon occasion, examination of effluents or river samples showed the presence of filamentous organisms microscopically resembling Sphaerotilus natans, however, these organisms were never detected in great numbers from river water samples, from scrapings of slimy material from aquatic vegetation, from various objects in the river, or from the special tiles that were placed in the stream channel. Some zones through the critical section of the river showed abundant growth of aquatic vegetation on the stream bed which consisted predominantly of a pond weed (species of Potamogeton). These weeds had a slimy coating on their leaves that microscopic examination showed to consist of a variety of organisms of several types. The biological examinations also consistently showed evidence of algae capable of introducing oxygen into the river water during periods of photosynthetic activity.

Tittabawassee River

Field surveys were made to the Tittabawassee River during the summer and fall of 1961 and again in the spring and summer of 1962, for river observation and collection of biological samples for laboratory examination. These samples were collected from the river upstream from Midland at Currie Parkway bridge, in Midland at Benson Street bridge, from the Dow Chemical Company waste treatment plant effluent, from the river at several sampling stations below Midland down to the State Street bridge in Saginaw (M.P. 6.69). Also, on several occasions samples were collected from stations on the Pine and Chippewa Rivers which enter the Tittabawassee River at Midland. A total of fifty-seven samples of various types were collected and examined during this period. As with the Clinton River, no attempt will be made to present here the detailed data of all of the biological findings, but a summary and discussion of the general evaluation of the biological aspects of the Tittabawassee River will be presented.

Microscopic examination of the Dow Chemical Company final effluent samples showed the usual biological forms normally associated with an activated sludge waste treatment process. Examination of various river samples and scrapings from tiles placed in the river showed a variety of organisms to be present, with no group or species in a predominant form. In general, a decrease in the number of biological species was noted in the river below the Dow outfall to the Smith's Crossing bridge, with an increase from this point downstream. One algal bloom was observed during the summer of 1961, at the Currie Parkway sampling station above Midland, which was found to be due to a blue-green alga (species Oscillatoria). Field surveys failed to show evidence of either sludge deposition zones or observable heavy biological growths. Filamentous organisms resembling Sphaerotilus natans were found on occasion in effluent and river samples, but never in great numbers. However, on two occasions--in December, 1961 and in June, 1962--slime flocs were noticed in samples collected at Smith's Crossing which were identified as Sphaerotilus natans. As reported in Section VII, the June, 1962 sample was collected when some waste was bypassing the Dow treatment plant suggesting that biological growths can develop in the Tittabawassee River given the proper nutrient conditions. Biological examinations showed the presence of various types of algae capable of introducing oxygen into the river water during periods of photosynthetic activity.

Summary and Conclusions

To supplement the chemical and biochemical data collected during this investigation, several biological surveys were conducted on the Clinton and Tittabawassee Rivers. Both the field and laboratory procedures employed in collecting the biological data have been described.

Biological results from both rivers failed to show any specific organism present in overwhelming numbers, nor were there any extensive sludge deposits observed in either rivers. However, on the Clinton River excellent contact opportunity exists between the river water and various weeds, tree limbs, rocks, etc. with attached slime, suggesting that part of the BOD removal is due to biological extraction and accumulation.

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SECTION XII

BOD LITERATURE REVIEW

Much has been written on the BOD test and in recent years considerable laboratory work has been done on the characteristics of specific wastes. Here, the subject will be reviewed in two parts: a) the BOD Test, and b) River BOD Abnormalities.

The BOD Test

One of the early classical works on the subject is that of Streeter and Phelps(1) in their study of the Ohio River. Phelps presented his basic deoxygenation law following the monomolecular reaction and indicated an approximate k_r value of 0.1 at 20°C. After this in 1927, another comprehensive report on the subject was written by Theriault;(2) an excellent historical summary of the BOD concept is presented in the first part of the report, followed by a detailed consideration of the BOD law as proposed by Phelps including agreement with Phelps' proposal.

Next in time is Phelps'(3) book on "Stream Sanitation" which reviews and consolidates the thinking of the profession to 1944, including a detailed discussion of the BOD test and concept. Moreover, the relation of BOD to the overall oxygen balance of a stream is clearly presented.

In 1946 an excellent report of the National Research Council(4) was published presenting BOD k_1 rate information on sewage from military installations. It is of interest to note that the k_1 rate varied from 0.1 to 0.3 at 20°C with an average reported value of 0.18; apparently military sewage is more rapidly oxidized than ordinary domestic sewage. Also, the question was raised as to the adequacy of the 5-day BOD as a measure of plant efficiency, particularly if the k_1 rate of the influent and effluent are not the same.

Gotaas,(5) as part of his doctoral work at Harvard, made a comprehensive study of the effect of temperature on the BOD reaction. He questioned the k_1 value of 0.1 at 20°C found by Phelps(1) and Theriault,(2) finding that for the dilute sewage with which he was working it was nearer 0.19 at 20°C. Further, he refined the temperature adjustment for k_1 which was proposed by

Streeter and Phelps(1) and, also, on the basis of his work disagreed with earlier proposals that the ultimate BOD value L was increased 2 per cent for each degree change in temperature.

Another interesting study was conducted by Williams(6) as part of his graduate work at the University of Minnesota concerning the significance of the velocity constant in stream analysis. Much work was done in the analysis of the effluent k_1 rate of the Minneapolis-St. Paul sewage treatment plant and an attempt was made to relate this to the resulting conditions of the Mississippi River below the plant. Unfortunately, most of the BOD rate velocity constants were computed from two or three points and solid conclusions were not possible; however, his information indicated that a rate other than 0.1 did apply to the plant effluent.

In 1953 Hoover, Jasewicz, and Porges(7) proposed "The BOD test consists of two biochemical reactions--first, the rapid growth of cells with assimilation of available nutrient into the cells, and second, the subsequent slow endogenous respiration of these cells." This partially refutes the monomolecular theory; however, they say the endogenous respiration stage is essentially monomolecular in nature with the first or assimilation stage coming to completion within 24 hours.

In the same year Ludzack, Moore, and Ruchhoft(8) made a comparative study of derivation procedures for BOD velocity constants. They concluded that the moment method was superior to the slope method; however, no mention was made of the graphical method proposed by Lee.

Considering another aspect, Balmat,(9) working in the laboratory at Rutgers University, analyzed the BOD rate characteristics of different fractions of domestic sewage obtaining k_1 values ranging from 0.08 for the settleable fraction to 0.39 for the soluble fraction. Unfortunately, the original data were not reproduced in his article so that the number and magnitude of observations which were used in computing his k_1 values are not known.

At the oxygen seminar held at Cincinnati in 1957, Schroepfer(10) stated that a characteristic of the deoxygenation constant is its inconstancy. He further indicated that the deoxygenation constants of plant effluents from intermediate and secondary treatment are materially different from those which result from primary treatment.

As part of the Low-Flow Augmentation project at the Johns Hopkins University, C. Hull(11) prepared a bibliography on biochemical oxygen demand in February, 1961, listing most of the important publications in this field since the Theriault publication in 1927.

Clark(12)(13)(14 at New Mexico State University described a continuous recording BOD apparatus using a sealed digestor assembly, involving a procedure for producing oxygen by electrolysis and measuring the amount of this oxygen added to the assembly to replace oxygen utilized in the substrate.

Following this, Eye(15) and his associates at the University of Cincinnati reported on another system for measuring BOD involving a sealed Erlenmeyer flask containing a platinum electrode system for oxygen measurements.

Busch(16)(17)(18)(19)(20)(21)(22) and his associates at Rice University have presented a series of papers dealing with BOD progression in soluble substrates. He, in effect, agrees with the theory of Hoover, Jasewicz, and Porges(7) presuming, first, rapid assimilation of the food by the cells and then a slower respiration.

Lordi and Heukelekian(23) presented a paper at Purdue University in 1961 on the effect of the rate of mixing on deoxygenation of polluted waters, and concluded that the deoxygenation rate was definitely increased with mixing.

Schroepfer(24)(25) and his associates discuss the matter of k_1 rates of sewage, effluents, and receiving waters in connection with their studies of the Mississippi River in the vicinity of Minneapolis and St. Paul.

Other pertinent references on the BOD test have been included in this report in Section VI on "BOD Procedures," and Section VII on "Comparison of Mathematical and Graphical Evaluation of BOD Velocity Constant k_1" and will not be repeated here.

River BOD Abnormalities

Many references have been made to so-called river BOD abnormalities, i.e., where a k_r rate other than 0.1 at 20°C is observed based on river BOD and time of passage information. In some cases the abnormality can be specifically identified as due to sludge deposits, or biological extraction, or immediate demand, but in most cases there is not enough reported information.

One of the earlier reports is that of Streeter(26) describing the results of experimental channel studies conducted at Cincinnati. Working with an experimental channel 2" wide, 6" deep (flow depth), 4,320 feet long, and a mixture of settled Ohio River water and sewage, he reports average decreasing k_r values of 21.1 in the first section of channel to 0.21 in the last section. Further, he reports extensive biological growths attached to the sides and bottom of the channel, clearly indicating these drops are partially due to biological extraction and accumulation.

Streeter(27) again in 1935 wrote a comprehensive paper on the Oxygen demand factor in polluted streams, where he expanded at length on various BOD abnormalities, including a mathematical formulation of the demand from sludge deposits. Also, reference is made to biological adsorption, immediate demand, two-stage reaction, etc.

Probably the most complete study which has been reported involving a BOD abnormality is that of Kittrell and Kochtitzky.(28) Here, the authors made a detailed analysis of a shallow, turbulent stream of the T.V.A. system. k_r values computed for each small river section decreased from 2.25 at 20°C in the section immediately below the largest source of pollution to 0.017 in the last section downstream. Moreover, reference is made to the presence of biological slimes attached to the stream bed; the authors state these slimes are probably responsible for the high BOD removal.

Kaplovsky, Mandel, Camper, and Murphy(29) in a survey of the Red Clay Creek drainage basin report the observation of slime growth on the shallow stream bottom. Within a very short stretch of stream relatively high BOD removal is accomplished. Working with average reported BOD and time of passage data it appears that k_r falls within the range of 0.72 to 0.94.

Another study where a shallow stream was involved is that of Gaufin and Tarzwell.(30) These biologists found that in Lytle Creek, Ohio, approximately 80 per cent BOD reduction was accomplished in the first three miles of stream below the sewage treatment plant. Working with the limited BOD and time of passage data reported, it appears that during low flows the k_r value falls approximately within the range of 0.35 to 0.47.

More recently, Eckenfelder and O'Connor,(31) as part of their book on "Biological Waste Treatment" discuss the various factors that might contribute to the river k_r.

Many additional articles have been written on the subject of BOD; however, an attempt has been made to select those which are pertinent to the research.

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SECTION XIII

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Donna Bacon	Draftsman
Richard Borton	Laboratory Assistant
Rollin Fender	Laboratory Assistant
Norman Herr	Laboratory Assistant
Janice Powers	Draftsman
Joseph Schwerha	Sanitary Chemist
Josephine Toney	Statistical Assistant

Finally, particular thanks are due to Mrs. Gladys Smith who is responsible for typing this report.

APPENDIX I Clinton River, Michigan

I - A	Intensive River Survey Data August 23-25, 1960
I - B	BOD Rate Summaries
I - C	River Survey Data July 12, 1961

CLINTON RIVER SURVEY DATA
August 23 to 25, 1960

Station 1 - MP 46.50 - Small Bridge (immediately upriver from Pontiac STP)

Date	Time of Collection	Temp°C	pH	BOD mg/1	DO mg/1
8-23	8:45A	24.0	8.0	4.81	6.86
	11:25A	24.0	8.2	3.25	9.75
	4:10P	22.5	8.1	2.75	7.85
	8:10P	21.0	7.9	2.78	5.18
8-24	12:15A	20.0	7.95	3.35	4.95
	4:20A	19.5	7.8	4.9	4.4
	8:05A	19.3	8.1	3.3	6.75
	12:26P	22.5	8.4	3.05	11.1
	4:15P	23.0	8.5	2.6	9.3
	8:03P	21.0	8.15	3.65	5.15
8-25	12:20A	20.0	7.82	3.15	4.6
	7:00A	19.5	7.82	2.9	5.1

Station 2 - MP 44.87 - M59 and M24 Intersection Bridge

Date	Time of Collection	Temp°C	pH	BOD mg/1	DO mg/1
8-23	8:55A	21.5	7.9	13.25	4.2
	11:40A	23.5	7.4	10.1	4.95
	4:20P	22.5	7.6	11.5	5.05
	8:25P	21.0	7.6	10.0	4.4
8-24	12:35A	20.0	7.75	11.85	4.0
	4:50A	19.5	7.7	9.0	3.8
	8:20A	19.8	7.7	12.0	4.1
	12:39P	22.0	7.75	10.15	5.7
	4:30P	23.0	7.7	4.9	5.3
	8:15P	22.0	7.7	16.0	4.3
8-25	12:40A	20.0	7.5	11.25	3.8
	7:12A	19.5	7.56	11.75	4.1

CLINTON RIVER SURVEY DATA (continued)
August 23 to 25, 1960

Station 3 - MP 43.37 - Auburn Heights Gage Bridge

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	9:05A	21.0		7.4	1.6
	11:50A	23.0		7.4	2.1
	4:30P	23.5		8.4	1.7
	8:40P	23.0		12.65	.5
8-24	1:00P	18.0		7.2	.65
	5:10A	18.8		6.3	.5
	8:33A	19.1		4.8	1.6
	12.51P	22.5		5.2	2.9
	4:40P	23.0		4.65	2.0
	8:25P	23.0		4.25	1.4
8-25	12:55A	20.0		7.0	1.0
	7.22A	18.5		5.4	1.0

Station 4 - MP 42.99 - Squirrel Road Bridge

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	9:25A	21.0		7.50	2.35
	12:00N	22.5		5.0	2.8
	4:40P	23.5		7.86	2.1
	8:55P	22.0		6.25	1.15
8-24	1:25A	20.0		7.6	1.18
	5:25A	18.8		7.0	.7
	8:44A	19.0		4.8	1.9
	1:02P	22.0		5.0	3.4
	4:55P	23.5		9.2	2.1
	8:35P	22.0		5.35	1.0
8-25	1:10A	19.5		5.0	2.3
	7:35A	18.5		5.2	1.4

CLINTON RIVER SURVEY DATA (continued)
August 23 to 25, 1960

Station 5 - MP 41.95 - Hamlin Street Bridge

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	9:35A	21.0	7.8	7.2	2.98
	12:15P	22.5	7.55	4.9	4.1
	4:55P	23.5	7.7	6.4	1.95
	9:10P	22.0	7.55	7.44	.3
8-24	1:40A	19.5	7.7	5.2	.42
	5:45A	18.8	7.6	5.2	.7
	8:56A	19.0	8.05	3.9	2.3
	1:13P	22.0	7.9	4.0	5.0
	5:10P	23.0	7.75	4.9	2.1
	8:50P	22.0		5.85	0
8-25	1:20A	20.0	7.49	6.6	1.2
	7:45A	18.5	7.53	3.6	1.6

Station 6 - MP 39.78 - Adams Street Bridge

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	9:50A	21.0		8.32	3.4
	12:35P	21.5		8.06	4.45
	5:10P	22.0		4.8	4.1
	9:30P	21.0		3.3	1.7
8-24	1:55A	20.0		4.1	1.76
	6:00A	19.1		7.2	2.0
	9:08A	18.9		6.1	2.7
	1:27P	21.5		4.7	5.5
	5:20P	22.0		1.75	5.2
	9:00P	21.5		2.0	3.35
8-25	1:35A	20.0		6.2	1.6
	7:55A	18.5		7.5	2.5

CLINTON RIVER SURVEY DATA (continued)
August 23 to 25, 1960

Station 7 - MP 36.27 - Livernois Street Bridge

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	10:10A	21.5		1.47	7.32
	12:50P	22.5		1.55	9.7
	5:30P	22.5		2.2	9.9
	10:10P	21.0		1.75	5.15
8-24	2:15A	19.0		1.73	3.46
	6:20A	19.0		1.3	3.3
	9:25A	19.7		1.07	5.8
	1:41P	22.5		1.7	11.5
	5:35P	23.0		1.0	11.5
	9:15P	21.5		2.5	6.15
8-25	1:45A	19.0		1.9	3.7
	8:06A	19.0		1.9	4.6

Station 8 - MP 34.98 - Low Bridge immediately west of hgw. M-150

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	10:25A	21.5		1.85	7.55
	1:20P	22.5		1.63	9.13
	5:50P	22.0		1.9	8.95
	10:30P	23.0		1.78	6.28
8-24	2:45A	19.5		2.3	5.6
	6:38A	18.8		1.9	5.4
	9:40A	19.8		1.63	6.325
	2:10P	22.5		4.65	10.0
	5:55P	23.0		1.7	9.6
	9:30P	21.0		2.95	7.5
8-25	2:00A	19.0		1.45	5.5
	8:18A	18.5		.8	5.4

CLINTON RIVER SURVEY DATA (continued)
August 23 to 25, 1960

Station 9 - MP 31.71 - Yates Mill Bridge

Date	Time of Collection	Temp °C	pH	BOD mg/l	DO mg/l
8-23	11:40A	23.0		1.95	8.6
	4:00P	23.5		3.45	8.4
	7:40P	22.0		2.6	7.6
8-24	8:30A	19.0	8.2	2.5	7.6
	1:15P	22.0		2.65	9.4

CLIMATOLOGICAL DATA

August 23, 1960 Sunrise 5:11 A.M. Sunset 6:53 P.M.
Maximum Temp. 83°F. Minimum Temp. 60°F. Average Temp. 72°F.
Sunshine 7 hrs. and 10 minutes 53% of possible No precipitation

August 24, 1960 Sunrise 5:12 A.M. Sunset 6:51 P.M.
Maximum Temp. 77°F. Minimum Temp. 56°F. Average Temp. 67°F.
Sunshine 9 hrs. and 54 minutes 73% of possible No precipitation

August 25, 1960 Sunrise 5:14 A.M. Sunset 6:51 P.M.
Maximum Temp. 80°F. Minimum Temp. 56°F. Average Temp. 68°F.
Sunshine 13 hrs. and 10 minutes 98% of possible No precipitation

BOD RATE SUMMARIES

River Clinton

Station Beaudette Park Bridge

Number (1)	Date 1960 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
F'	7-19	-	60	22	20	-	40.91	normal	4	2.37	5.47	6.78	.07
J'	7-19	-	60	22	37	-	21.84	hot	4	3.25	5.74	8.04	.16
I'	7-19	-	60	22	13	-	56.91	cold	4	1.32	2.16	6.98	.07
2	7-26	-	60	25	20	-	84.91		6	2.39	3.98	10.40	.05

BOD RATE SUMMARIES

River Clinton　　Station Plant Bridge

Number	Date 1960-1962	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
S	6-7	-	99	22.5	20	-	75.45		9	8.81	11.97	24.56	.06
V	6-22	-	90	20.5	20	-	22.51		9	6.74	10.12	14.47	.14
Θ	6-29	-	66	24	20	-	19.67		8	3.78	6.80	6.09	.03
K	7-6	-	71	22	20	-	34.85	normal	6	4.66	7.51	12.67	.07
π	7-6	-	71	22	37	-	25.59	hot	9	6.92	10.77	15.62	.12
μ	7-6	-	71	22	13	-	57.89	cold	6	2.84	4.61	11.55	.04
G'	7-19	-	60	25	20	-	40.88	normal	4	4.44	6.67	11.85	.11
Q'	7-19	-	60	25	37	-	16.74	hot	5	6.48	10.17	12.05	.22
O'	7-19	-	60	25	13	-	40.91	cold	4	3.23	4.33	9.70	.01
3	7-26	-	39	23	20	-	84.90		6	3.45	5.71	11.60	.08
	5-11	9:45A	155	13.5	20	10.40	6.74		10	4.20	-	4.30	.05
4	6-22	9:38A	69	20	20	7.39	6.72		10	3.58	-	4.26	.08
13	6-27	8:35A	41	19.5	20	9.11	7.83		12	3.11	-	4.67	<.01
26	7-12	7:25A	39	23	20	6.65	6.58		12	5.92	-	7.02	.13
65	8-16	1:00P	36	24.5	20	9.62	5.70		11	2.68	-	2.82	.17
78	11-7	10:30A	40	-	20	9.80	13.88		9	3.45	5.84	7.75	.23
86	12-18	10:55A	75	1.0	20	13.10	14.62		12	1.84	3.10	4.30	.14
97	1-31	10:20A	66	0.0	20	13.20	13.90		10	1.50	2.31	3.00	.16
105	3-7	10:30A	104	1.5	20	12.50	13.65		9	2.59	4.71	6.65	.12

BOD RATE SUMMARIES

River Clinton

Station Plant Bridge

Number (1)	Date 1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. oC. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
113	4-11	9:50A	151	7	20	11.70	13.71		9	3.42	5.38	7.45	.09
122	5-9	12:30P	78	15	20	10.85	14.64		10	4.05	6.91	10.05	.09
126	6-13	9:45A	58	17	20	8.00	13.67		10	7.37	12.23	17.00	.07
137	7-17	7:45A	35	22	20	6.55	13.70		11	2.68	4.09	5.50	.10

BOD RATE SUMMARIES

River Clinton

Station Pontiac WTP - Primary Effluent

Number	Date 1960	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1 1st 5 Days	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
E	6-9	-	74	19	20	-	9.09		15	27.85		50.32	.17

BOD RATE SUMMARIES

River Clinton

Station Pontiac WTP - Imhoff Effluent

Number	Date 1960	Time Collected	Runoff cfs	Temp. ^{o}C.	Incubation Temp. ^{o}C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1 1st 5 Days	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
F	6-15	-	79	21.5	20	-	6.70		23	34.32	-	40.62	.14
I	6-15	-	79	18.0	20	-	7.40		24	31.17	-	39.70	.15

BOD RATE SUMMARIES

River Clinton

Pontiac WTP
Station Trickling Filter Effluent

Number	Date 1960-1961	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1 1st 5 Days	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
H	6-15	-	79	21.5	20	-	14.29	chlor.	17	24.38	38.03	57.66	<.01
G	6-15	-	79	21.5	20	-	6.68	de-chlor.	26	28.11	-	35.72	.17
μ	6-29	-	66	23.5	20	-	11.38	100% chlor.	12	6.32	17.19	18.81	<.01
γ	6-29	-	66	23.5	20	-	6.92	100% de-chlor.	22	23.35	-	33.69	<.01
ϵ	6-29		66	23.5	20	-	12.68	chlor. 50% waste 50% river	15	7.54	13.70	19.14	<.01
β	6-29	-	66	23.5	20	-	13.44	de-chlor. 50% waste 50% river	17	15.86	26.29	30.01	<.01
δ	6-29	-	66	23.5	20	-	33.73	chlor. 25% waste 75% river	12	5.21	9.90	27.60	<.01
α	6-29	-		23.5	20	-	76.49	de-chlor 25% waste 75% river	16	10.69	20.88	34.47	<.01
	4-7	11:10A	65	12.8	20	6.30	4.97		9	32.47-	-	32.47	.13
39	7-18	7:50A	35	21.5	20	5.26	6.76		12	20.37	-	22.13	<.01

BOD RATE SUMMARIES

River Clinton

Station Pontiac WTP Activated Sludge Effluent

Number	Date 1960-1961	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1 1st 5 Days	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
D	6-9	-	74	19	20	-	53.58		14	20.16	29.40	39.62	<.01
W	6-22	-	90	23.5	20	-	14.38	100% waste	14	31.96	40.72	43.45	<.01
X	6-22	-	90	23.5	20	-	18.60	50% waste 50% river	20	31.22	37.68	41.39	<.01
Y	6-22	-	90	23.5	20	-	22.40	25% waste 75% river	15	19.06	24.24	28.77	.06
σ	7-6	-	71	22	20	-	7.49	normal	14	28.31	-	32.71	.02
λ	7-6	-	71	24	37	-	14.56	hot	11	7.80	20.92	22.96	.15
Ø	7-6	-	71	24	13	-	12.86	cold	12	17.35	29.15	30.54	<.01
	3-23	10:25A	116	15.2	20	1.69	10.80	stirred	11	18.17	21.87	22.38	.14
	3-23	10:25A	116	15.2	20	1.69	6.03	non-stirred	11	14.73	-	16.47	<.01
	4-13	9:50A	55	13	20	3.23	6.78	stirred nonfiltered	11	10.49	-	12.44	.13
	4-13	9:50A	55	13	20	3.23	6.78	non-stirred nonfiltered	11	5.59	-	6.74	.06
	4-26	11:05A	239	12.2	20	1.70	6.75	stirred filtered	12	4.82	-	8.71	.02
	4-26	11:05A	239	12.2	20	1.70	6.75	stirred nonfiltered	12	15.21	-	16.72	.14
	4-26	11:05A	239	12.2	20	1.70	6.75	non-stirred nonfiltered	12	11.80	-	12.83	.05
	5-11	10:20A	155	17	20	4.10	6.74	stirred 100%	10	12.50	-	14.25	.10
	5-11	10:20A	155	17	20	4.10	6.74	non-stirred 100%	10	11.05	-	12.80	.07
	5-11	10:20A	155	15.5	20	6.70	6.74	stirred 50% waste 50% river	10	10.91	-	14.15	.11

BOD RATE SUMMARIES

River Clinton

Station Pontiac WTP Activated Sludge Effluent

Number	Date 1961	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10_5} mg/1 1st 5 Days	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	5-11	10:20A	155	15.5	20	6.70	6.74	nonstirred 50% waste 50% river	10	8.70	-	10.60	.04
	5-24	10:00A	69	19	20	1.10	6.80	stirred	12	24.03	-	26.35	<.01
	5-24	10:00A	69	19	20	1.10	6.80	nonstirred	12	13.40	-	19.65	<.01
	5-24	10:00A	69	19	20	1.10	6.80	75%, 50%, 25%, 15%	12	13.67	-	17.50	<.01
	6-1	10:00A	154	20.5	20	1.90	4.77	stirred chlor.	9	1.70*	-	1.70	.17
	6-1	10:00A	154	19.5	20	1.90	4.77	Stirred chlor. 50% waste 50% river	9	6.30*	-	6.30	<.01
	6-7	10:25A	50	20	20	2.40	6.76	stirred 100% de-chlor.	9	17.74	-	24.60	<.01
	6-7	10:25A	50	20	20	2.40	6.76	nonstirred 100% de-chlor.	9	16.48	-	27.55	<.01
	6-7	10:25A	50	20.5	20	6.60	6.76	stirred 50% waste 50% river	9	13.66	-	17.72	<.01
	6-7	10:25A	50	20.5	20	6.60	6.76	nonstirred 50% waste 50% river	9	7.25	-	10.95	<.01
34	7-12	10:45A	39	-	20	-	7.77		12	10.72	-	16.49	<.01
38	7-18	7:45A	35	22	20	4.66	6.76		12	6.61	-	8.61	<.01
77	11-7	9:55A	40	-	20	1.6	13.88		9	8.18	21.78	45.70	.02

*Approx.

BOD RATE SUMMARIES

River Clinton

Station Pontiac WTP
Activated Sludge Effluent

Number	Date 1961-1962	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD$_5$ mg/1	BOD$_{10}$ mg/1 1st 5 Days	BOD mg/1 Final	K$_1$ for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
85	12-18	10:45A	75	14.5	20	2.75	14.62		12	8.37	24.94	56.10	<.01
106	3-7	10:45A	104	14	20	3.00	18.62		9	6.83	26.16	59.90	<.01
114	4-11	10:00A	151	15	20	1.55	27.69		9	17.18	46.72	59.75	<.01
123	5-9	1:00P	78	19.5	20	1.00	14.64		10	11.20	38.45	58.30	<.01
127	6-13	10:15A	58	20	20	.90	13.67		10	11.64	35.17	55.00	<.01
138	7-17	8:00A	35	22	20	1.50	19.70		11	5.20	26.89	59.00	<.01
138	7-17	8:00A	35	22	20	1.50	13.70	100,75,50, 25,15 & 10%	11	3.83	18.67	69.00	.02
138	7-17	8:00A	35	22	20	1.50	13.70	settled	11	1.28	6.57	21.80	<.01
138	7-17	8:00A	35	22	20	1.50	13.70	filtered	11	1.26	1.73	2.45	.09
145	8-14	4:25P	29	23	20	1.00	145.53		10	13.13	35.87	59.65	<.01
151	8-23	11:00A	33	22	20	2.40	13.42	routine rate	7	7.29	11.32	12.15	<.01
151	8-23	11:00A	33	22	20	2.40	13.42	M.B. inhib.	7	2.69	5.95	8.40	.04
151	8-23	11:00A	33	22	20	2.40	13.42	pasteur. inhib.	7	1.64	2.92	3.30	.09
151	8-23	11:00A	33	22	20	2.40	13.42	acid. inhib.	7	1.95	3.15	4.15	.05

BOD RATE SUMMARIES

River Clinton

StationGrand Trunk R.R. Bridge

Number (1)	Date 1960 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
P	6-7	-	99	21	20	-	69.47		9	9.17	19.48	36.27	.07

BOD RATE SUMMARIES

River Clintons Station Updyke Bridge

Number	Date 1960	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
H'	7-19	11:00A	60	23	20	-	19.66	normal	5	8.65	14.81	18.01	<.01
Z'	7-19	11:00A	60	23	37	-	9.57	hot	5	6.67	13.64-	13.64	.14
Y'	7-19	11:00A	60	23	13	-	19.71	cold	4	3.76	8.46	13.61	<.01
O	7-26	-	39	24	20	-	4.96	20% waste 80% dil. H_2O	5	12.50*	-	12.50	<.01
K'	7-26	-	39	24	20	-	14.52		9	10.16	15.37	18.75	<.01
L'	7-26	-	39	24	20	-	12.40		9	11.63	18.10	21.30	<.01
P'	7-26	-	39	24	20	-	12.36		9	10.62	16.00	19.20	<.01
R'	7-26	-	39	24	20	-	14.55		9	11.42	16.27	20.20	<.01
S'	7-26	-	39	24	20	-	14.71		9	11.55	17.13	21.10	<.01
T'	7-26	-	39	24	20	-	14.68		9	10.93	15.96	19.85	<.01
U'	7-26	-	39	24	20	-	15.70		9	12.02	17.21	21.20	<.01
V'	7-26	-	39	24	20	-	14.72		9	11.33	16.71	20.35	<.01
W'	7-26	-	39	24	20	-	12.44		9	11.52	17.34	20.50	<.01
X'	7-26	-	39	24	20	-	14.76		9	11.73	16.80	20.65	<.01

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*Approx.

BOD RATE SUMMARIES

River Clinton

Station M-59 Bridge

Number	Date 1960	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
L	7-6	-	71	22	20	-	22.65	normal	7	8.74	14.24	19.39	<01
P	7-6	-	71	22	37	-	24.81	hot	8	6.44	15.08	19.83	.14
T	7-6	-	71	22	13	-	22.73	cold	6	3.54	7.99	14.15	<01
(11)	8-9	-	42	21	20	-	8.80		9	12.66	-	17.25	<01
(12)	8-9	-	42	21	20	-	6.99	20% river 80% dil.	7	13.03	-	15.00	.11
(13)	8-9	-	42	21	20	-	8.77		9	13.39	-	19.60	<01
(15)	8-9	-	42	21	20	-	8.80		9	12.42	-	18.65	<01
(19)	8-9	-	42	21	20	-	8.76		9	12.24	-	17.30	<01
(21)	8-9	-	42	21	20	-	8.80		9	13.25	-	18.40	<01
(23)	8-9	-	42	21	20	-	8.77		9	12.84	-	17.70	<01
(25)	8-9	-	42	21	20	-	8.80		9	12.66	-	17.55	<01
(26)	8-9	-	42	21	20	-	6.96	20% river 80% dil.	7	12.89	-	14.75	.19
(27)	8-9	-	42	21	20	-	8.76		9	12.43	-	17.25	<01
(28)	8-9	-	42	21	20	-	6.96	20% river 80% dil.	7	11.16	-	14.00	.21
(29)	8-9	-	42	21	20	-	6.96	20% river 80% dil.	6	11.39	-	14.00	.13

BOD RATE SUMMARIES

River Clinton

Station **M-59 Bridge**

Number (1)	Date 1960-1961 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
(30)	8-9	-	42	21	20	-	8.83		9	12.89	-	17.55	<.01
(31)	8-9	-	42	21	20	-	8.78		9	13.34	-	18.25	<.01
14	6-27	9:00A	41	20	20	3.85	7.66		12	10.23	-	17.73	<.01
27	7-12	7:50A	39	-	20	3.53	6.77		13	14.78	-	22.42	<.01
40	7-18	8:20A	35	22	20	4.05	6.76		12	10.14	-	16.20	.02
50	7-27	8:15A	34	22	20	3.83	13.25		11	13.38	24.31	29.26	<.01
50	7-27	8:15A	34	22	20	3.83	6.75	100,75,50 and 25%	13	14.41	-	27.80	<.01

BOD RATE SUMMARIES

River Clinton Station Auburn Heights

Number	Date 1960-1961	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
44	8-25	-	33	-	20	-	24.83		5	6.33	15.49	24.86	<.01
51	9-7		35	22	20	-	6.83	mixed	6	6.98	-	10.85	<.01
52	9-7	-	35	22	20	-	6.83	settled supernat.	6	6.29	-	8.95	<.01
	1-5	-	30	8.3	20	-	6.80	-	6	16.33	-	23.80	.06
7	6-22	10:45A	69	20	20	6.18	6.72	stirred	10	7.85	-	10.24	.09
7	6-22	10:45A	69	20	20	6.18	6.72	nonstirred	10	5.92	-	8.85	<.01
15	6-27	9:30A	41	20	20	3.14	7.56		11	4.38	-	12.76	.10
41	7-18	9:00A	35	22	20	1.62	6.76		12	3.78	-	8.30	<.01
51	7-27	8:40A	34	22	20	1.01	13.25	nonstirred	9	3.95	16.48	21.20	<.01
51	7-27	8:40A	34	22	20	1.01	9.84	stirred	9	8.79	13.64	13.64	.11
51	7-27	8:40A	34	22	20	1.01	8.04	100%,75%, 50%	10	6.62	-	15.22	<.01
51	7-27	8:40A	34	22	20	1.01	5.74	lights	10	-11.99	-	-14.61	-
53	8-2	10:20A	47	22	20	1.16	5.99	normal	11	12.80	-	17.38	<.01
53	8-2	10:20A	47	22	33	1.16	5.99	hot	11	18.80	-	20.01	.02
53	8-2	10:20A	47	22	10	1.16	5.99	cold	11	5.32	-	7.23	<.01
63	8-16	11:00A	36	23.5	20	1.81	5.70		11	4.03	-	4.69	<.01
72	9-6	9:30A	59	22	20	1.31	7.97	normal	14	10.17	-	16.58	<.01
72	9-6	9:30A	59	22	20	1.31	7.97	daylight dark	14	5.87	-	2.87	<.01
72	9-6	9:30A	59	22	20	1.31	8.98	daylight dark dil.	14	5.58	-	8.04	<.01

BOD RATE SUMMARIES

River Clinton Station Auburn Heights

Number	Date 1961-1962	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
72	9-6	9:30A	59	22	20	1.31	8.74	75,50 & 25%	13	9.73	-	28.60	<.01
72	9-6	9:30A	59	22	20	1.31	7.00	75,50 & 25% lights 24 hours	-	<0 at 3.9 days	-	-	-
72	9-6	9:30A	59	22	20	1.31	4.97	lights 24 hours	-	<0 at 3.2 days	-	-	-
79	11-7	11:45A	40	-	20	6.25	13.88		9	6.11	16.08	17.60	<.01
87	12-18	11:10A	75	2.5	20	9.90	14.62	normal	12	5.56	15.61	17.55	<.01
87	12-18	11:10A	75	2.5	30	9.90	14.62	hot	12	12.31	17.61	19.85	<.01
87	12-18	11:10A	75	2.5	2.5	9.90	14.62	cold	12	.20	.82	1.45	-
99	1-31	11:15A	66	.25	20	11.00	13.90	normal	10	3.89	17.51	19.75	<.01
99	1-31	11:15A	66	.25	30	11:00	13.90	hot	10	14.92	19.37	23.75	<.01
99	1-31	11:15A	66	.25	.25	11.00	13.90	cold	10	.41	1.58	1.95	-
107	3-7	11:30A	104	4	20	10.10	13.65	normal	9	2.67	9.27	14.90	<.01
107	3-7	11:30A	104	4	30	10.10	13.65	hot	9	6.27	15.87	18.05	<.01
107	3-7	11:30A	104	4	4	10.10	13.65	cold	9	.20	1.06	1.35	-
115	4-11	10:30A	151	8	20	10.80	13.71	normal	9	4.19	11.62	14.30	<.01
115	4-11	10:30A	151	8	30	10.80	13.71	hot	9	9.68	12.64	15.95	<.01
115	4-11	10:30A	151	8	8	10.80	13.71	cold	9	1.30	2.11	2.45	.07
124	5-9	1:45P	78	17.5	20	7.15	14.64	normal	10	9.36	19.97	23.25	<.01
124	5-9	1:45P	78	17.5	30	7.15	14.64	hot	10	17.91	24.99	29.10	<.01

BOD RATE SUMMARIES

River Clinton

Station Auburn Heights

Number (1)	Date 1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. oC. (5)	Incubation Temp. oC. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
124	5-9	1:45P	78	17.5	17.5	7.15	14.64	cold	10	8.69	21.45	23.75	<.01
128	6-13	11:00A	58	17	20	3.15	13.67	normal	10	5.62	15.55	17.35	<.01
128	6-13	11:00A	58	17	30	3.15	13.67	hot	10	14.77	20.44	23.75	<.01
134	6-26	10:30A	58	21.5	20	2.25	12.75		11	6.63	16.73	17.90	<.01
134	6-26	10:30A	58	21.5	20	2.10	12.75		11	6.76	16.57	17.80	<.01
134	6-26	10:30A	58	21.5	20	2.05	12.75		11	6.88	16.13	17.25	<.01
134	6-26	10:30A	58	21.5	20	2.30	12.75		11	7.21	16.91	18.05	<.01
134	6-26	10:30A	58	21.5	20	2.30	12.75		11	6.72	16.09	17.20	<.01
139	7-17	8:45A	35	20.5	20	0.60	19.70		11	2.56	12.00	28.00	<.01
139	7-17	8:45A	35	20.5	20	0.60	12.70	100,75,50,25%	12	2.71	7.43	9.20	<.01
139	7-17	8:45A	35	20.5	20	0.60	13.70	settled	11	1.98	10.90	19.45	<.01
139	7-17	8:45A	35	20.5	20	0.60	13.70	filtered	11	2.08	10.99	21.00	.03
146	8-14	12:15P	29	20	20	2.40	166.50		10	2.47	11.44	53.96	<.01
152	8-23	10:45A	33	23	20	2.30	13.42	routine rate	7	3.64	13.92	17.65	.03
152	8-23	10:45A	33	23	20	2.30	13.42	M.B. inhib.	7	1.69	4.28	9.05	<.01
152	8-23	10:45A	33	23	20	2.30	13.42	pasteur. "	7	1.32	2.98	4.50	<.01
152	8-23	10:45A	33	23	20	2.30	13.42	acid. "	7	1.07	2.12	2.20	<.01

BOD RATE SUMMARIES

River Clinton

Station Adams St. Bridge

Number (1)	Date 1960-1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
E'	7-19		60	22	20		30.61	normal	4	6.23	10.91	14.14	<.01
N'	7-19		60	22	37		14.80	hot	4	4.43	10.50	12.77	.15
M'	7-19		60	22	13		19.66	cold	4	2.05	14.70	9.94	<.01
1	7-26		39	22	20		54.85		7	7.12	14.71	20.95	<.01
53	9-7		35	20.5	20		41.92	mixed samp.	6	7.79	12.13	14.40	<.01
54	9-7		35	20.5	20		6.83	{settled	6	7.24	-	11.10	<.01
	1-5		30	5.9	20		6.79	supernat.	7	13.84	-	21.25	<.01
42	7-18	10:35A	35	21	20	3.34	6.76		12	7.09	-	13.98	<.01
52	7-27	9:20A	34	22	20	2.42	13.25		9	7.57	15.97	17.18	<.01
52	7-27	9:20A	34	22	20	2.42	6.04	100,75&25%	12	12.56	-	15.02	<.01
54	8-2	11:10A	47	22	20	2.02	5.99	normal	12	13.53	-	16.65	<.01
54	8-2	11:10A	47	22	33	2.02	5.99	hot	12	15.98	-	18.04	.07
54	8-2	11:10A	47	22	10	2.02	5.99	cold	11	3.84	-	5.25	<.01
64	8-16	11:45A	36	22.5	20	4.53	5.70		11	6.70	-	8.31	<.01
80	11-7	12:15P	40	-	20	6.20	13.88		9	7.65	14.47	15.60	<.01
88	12-18	11:30A	75	2.5	20	9.70	14.62		12	5.16	12.20	13.60	<.01
100	1-31	11:45A	66	0.0	20	11.70	12.88		10	4.99	15.91	18.20	.03
108	3-7	12 noon	104	4	20	10.15	13.65		9	6.66	10.97	12.35	<.01

BOD RATE SUMMARIES

River Clintonㅤ Station Adams St. Bridge

Number (1)	Date 1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
116	4-11	11:15A	151	8	20	10.20	13.71		9	5.60	10.33	11.75	<.01
125	5-9	2:15P	78	16	20	8.10	14.64		10	6.50	9.86	11.35	<.01
129	6-13	12 noon	58	17	20	3.40	13.67		10	8.30	14.98	16.25	<.01
140	7-17	9:15A	35	20.5	20	1.85	12.70		11	9.40	17.08	20.50	<.01
147	8-14	10:45A	29	18.5	20	2.90	13.50		10	6.36	14.68	17.50	<.01
153	8-23	1:30P	33	22.5	20	4.10	13.42	routine rate	7	8.56	16.55	18.20	<.01
153	8-23	1:30P	33	22.5	20	4.10	13.42	M.B. inhib.	7	2.98	10.22	16.20	<.01
153	8-23	1:30P	33	22.5	20	4.10	13.42	pasteur. "	7	1.02	2.15	5.80	<.01
153	8-23	1:30P	33	22.5	20	4.10	13.42	acid "	7	.92	1.62	1.65	.15

CLINTON RIVER SURVEY DATA

July 12, 1961

Time of Collection	Temp ^{o}C	pH	Chlorine Residual mg/l	DO mg/l	BOD_5 mg/l
Trickling Filter Effluent - Pontiac Waste Treatment Plant (After chlorination)					
7:28A	21.0	7.3	0.6	5.92	
9:30A	21.5	7.2	0.65	5.87	
11:11A	21.5	7.3	0.6	6.07	
1:46P	23.5	7.4	0.55	5.47	
2.48P	23.0	7.3	0.55	5.37	
5.25P	23.0	7.6	0.6	5.36	
Activated Sludge Effluent - Pontiac Waste Treatment Plant (Before chlorination)					
7:42A	22.0	7.45	0	1.06	
9:32A	22.0	7.4	0	1.21	
11:15A	22.5	7.4	0	1.42	
1:50P	23.0	7.6	0	1.62	
3:04P	23.0	7.5	0	1.21	
5:28P	22.5	7.7	0	1.11	
Activated Sludge Effluent - Pontiac Waste Treatment Plant (Above weir in Cl contact tank after chlorination)					
7:47A	22.0	7.6	0.35	1.77	
9:35A	22.0	7.6	0.35	1.82	
11:17A	22.0	7.5	0.25	1.72	
1:55P	22.5	7.5	0.30	1.97	
3:07P	22.5	7.5	0.30	1.72	
5:31P	22.5	7.7	0.25	1.62	
Activated Sludge Effluent - Pontiac Waste Treatment Plant (Below weir in Cl contact tank after chlorination)					
7:53A	22.0	7.6	0.2	5.41	
9:40A	22.0	7.6	0.25	5.01	
11:22A	22.0	7.5	0.20	4.96	
1:58P	22.5	7.6	0.25	5.06	
3:11P	22.0	7.5	0.30	4.10	
5:35P	22.5	7.7	0.25	3.95	

CLINTON RIVER SURVEY DATA (Continued)

July 12, 1961

Time of of Collection	Temp °C	pH	Chlorine Residual mg/l	DO mg/l	BOD$_5$ mg/l
M.P. 46.50 - Small Bridge (Upstream from Pontiac STP and below E. Blvd. bridge)					
7:25A	23.0	8.2	0	6.65	9.06
10:00A	24.0	8.3	0	9.42	
11:37A	24.0	8.2	0	9.92	
2:15P	24.5	8.35	0	10.83	
3:40P	24.0	8.5	0	10.33	
5:50P	23.5	8.3	0	9.01	
M.P. 46.39 - River about 50 ft. below Pontiac STP effluent discharge point (by wading)					
8:00A	22.0	7.8	0.15	7.18	
9:45A	——	7.7	0.20	7.19	
11:26A	22.0	7.7	0.25	7.59	
2:00P	23.0	7.8	0.25	7.44	
3:17P	23.0	7.7	0.30	7.29	
5:40P	22.5	7.8	0.20	7.19	
M.P. 45.89 - River Upstream from Grand Trunk R.R. bridge (by wading)					
8:40A	22.0	7.65	0.1	6.38	
10:13A	22.5	7.7	0.15	6.58	
11:50A	23.0	7.6	0.3	7.49	
2:28P	23.5	7.7	0.15	7.59	
4:02P	23.5	7.8	0.2	7.39	
6:00P	23.0	7.8	0.2	6.99	
M.P. 44.87 - M59 Highway Bridge					
7:50A	22.0	7.7		3.53	7.66
10:25A	23.0	7.6	0	4.55	
12 Noon	23.5	7.5	0	4.76	
2:40P	24.5	7.8	0	5.26	
4:12P	24.0	7.75	0	4.96	
6:07P	23.0	7.3	0	4.86	
M.P. 43.37 - Auburn Heights Gage Bridge					
8:15A	22.0	7.7		1.31	5.50
12:08P	23.0	7.5		2.13	
4:40P	25.0	7.6		1.82	
6:17P	24.5	7.5		0.81	

CLINTON RIVER SURVEY DATA (Continued)

July 12, 1961

Time of Collection	Temp °C	pH	DO mg/l	BOD_5 mg/l
M.P. 42.99 - Squirrel Road Bridge				
8:40A	22.0	7.7	1.71	4.08
M.P. 41.95 - Hamlin Street Bridge				
8:55A	22.0	7.8	1.51	4.42
M.P. 39.78 - Adams Street Bridge				
9:15A	22	7.9	2.52	5.05
M.P. 36.27 - Livernois Street Bridge				
9:40A	22	8.1	6.65	1.11
M.P. 34.98 - Low Bridge immediately west of highway M-150				
10:05A	22	8.1	6.85	2.22

APPENDIX II Tittabawassee River, Michigan

II - A Intensive River Survey Data
August 23-25, 1961

II - B BOD Rate Summaries

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 1 - Tittabawassee River above Midland at Currie Pkwy Bridge - Center (Above M-20 Br.)

Date	Time of Collection	Temp° C.	pH	D.O. mg/1	BOD mg/1				
					% Conc	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/1
8-23	8:25A	22.0		8.90	100	8.9	6.15	2.75	2.75
	12:20P	22.0		8.75	100	8.75	7.00	1.75	1.75
	4:05P	23.0		9.00	100	9.00	6.90	2.10	2.10
	8:15P	22.0		8.65	100	8.65	7.85	0.80	0.80
8-24	12:30A	22.0		8.85	100	8.85	6.20	2.65	2.65
	4:20A	21.0		7.45	100	7.45	4.78	2.67	2.67
	8:05A	21.0		7.30	100	7.30	3.05	4.25	4.25
	12.05P	22.0		7.55	100	7.55	5.80	1.75	1.75
	4:00P	22.0		9.00	100	9.0	6.60	2.40	2.40
	8:10P	22.0		8.70	100	8.70	2.40	6.30	6.30
8-25	12:05A	22.0		8.90	100	8.90	7.05	1.85	1.85
	4:05A	21.0		8.50	100	8.50	6.70	1.80	1.80

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 2 - Chippewa River at Homer Br. - Center

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD5 mg/l
8-23	8:40A	21.0		7.55	100	7.55	6.60	0.95	0.95
	12:30P	21.0		8.85	100	8.85	8.10	0.75	0.75
	4:20P	22.0		8.90	100	8.90	8.15	0.75	0.75
	8:30P	22.0		7.30	100	7.30	5.60	1.70	1.70
8-24	12:50A	20.0		7.10	100	7.10	5.85	1.25	1.25
	4:40A	21.0		6.80	100	6.80	6.20	0.60	0.60
	8:20A	20.0		7.20	100	7.20	6.25	0.95	0.95
	12:20P	22.0		9.70	100	9.70	9.00	0.70	0.70
	4:15P	22.0		11.25	100	11.25	9.85	1.40	1.40
	8:25P	22.0		8.30	100	8.30	7.35	0.95	0.95
8-25	12:20A	21.0		7.90	100	7.90	6.60	1.30	1.30
	4:20A	20.0		6.70	100	6.70	6.10	0.60	0.60

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 3 - Pine River at Frost Br. - Center

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD $_5$ mg/l
8-23	8:50A	21.0		6.50	100	6.50	0	6.50	6.50
					50	7.70	1.00	6.70	13.40
	12:45P	21.0	8.10	10.20	100	10.20	0.20	10.00	10.00
					50	8.30	1.50	6.80	13.60
	4:30P	21.0	8.15	9.85	100	9.85	0.50	9.35	9.35
					50	8.60	1.20	7.40	14.80
	8:50P	21.0	7.95	7.40	100	7.40	0.45	6.95	6.95
					50	6.95	0.85	6.10	12.20
8-24	1:10A	19.0	7.65	6.35	100	6.35	0	6.35	6.35
					50	7.45	1.05	6.40	12.80
	5:00A	20.0	6.90	5.80	100	5.80	0	5.80	5.80
					50	7.45	1.86	5.59	11.18
	8:30A	20.0	7.65	8.80	100	8.80	2.40	6.40	6.40
					50	8.90	3.20	5.70	11.40
	12:35P	22.0	8.10	15.90	100	15.90	4.90	11.00	11.00
					50	10.35	2.40	7.95	15.90
	4:30P	23.0	8.10	16.20	100	16.20	3.75	12.45	12.45
					50	10.10	3.40	6.70	13.40
	8:40P	22.0	8.05	11.15	100	11.15	1.55	9.60	9.60
					50	8.65	1.20	7.45	14.90
8-25	12:35A	21.0	7.50	8.30	100	8.30	0.15	8.15	8.15
					50	7.90	2.20	5.70	11.40
	4:35A	21.0	8.00	5.80	100	5.80	0	>5.80	5.80
					50	7.50	2.50	5.00	10.00

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 4 - Tittabawassee River at Benson St. Br. - 1/3 nearest Midland

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/l
8-23	9:10A	22.0		7.00	100	7.00	1.90	5.10	5.10
					50	7.80	4.85	2.95	5.90
	1:00P	22.0	8.10	7.90	100	7.90	0.86	7.04	7.04
					50	7.90	4.00	3.90	7.80
	4:50P	21.0	8.10	8.65	100	8.65	1.30	7.35	7.35
					50	8.10	3.50	4.60	9.20
	9:15P	21.0	8.20	6.50	100	6.50	0	6.50	6.50
					50	6.90	1.10	5.80	11.60
8-24	1:25A	20.0	8.20	7.40	100	7.40	1.75	5.65	5.65
					50	8.00	4.50	3.50	7.00
	5:20A	20.0	8.20	6.60	100	6.60	2.02	4.58	4.58
					50	7.95	3.80	4.15	8.30
	8:40A	20.0	8.25	7.65	100	7.65	3.95	3.70	3.70
					50	8.05	5.60	2.45	4.90
	12:40P	22.0	8.40	8.95	100	8.95	3.00	5.95	5.95
					50	8.40	4.70	3.70	7.40
	4:45P	22.0	7.90	12.20	100	12.20	1.45	10.75	10.75
					50	9:00	4:45	4:55	9.10
	8:55P	22.0	8.10	11.00	100	11.00	2.30	8.70	8.70
					50	8.50	4.05	4.45	8.90
8-25	12:55A	21.0	8.10	8.90	100	8.90	2.75	6.15	6.15
					50	8.25	4.60	3.65	7.30
	4:50A	21.0	8.00	7.20	100	7.20	2.60	4.60	4.60
					50	7.95	5.55	2.40	4.80

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 5 - Tittabawassee River at Benson St. Br. - 1/3 farthest from Midland

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final	Depl.	BOD_5 mg/l
8-23	9:15A	22.0		6.40	100	6.40	2.10	4.30	4.30
	1:10P	22.0		7.90	100	7.90	3.85	4.05	4.05
	5:00P	21.0		8.60	100	8.60	3.23	5.35	5.35
	9:30P	21.0		6.50	100	6.50	0	6.50	6.50
8-24	1:30A	20.0		7.20	100	7.20	3.35	3.85	3.85
	5:25A	20.0		6.45	100	6.45	2.95	3.50	3.50
	8:50A	20.0		7.10	100	7.10	3.60	3.50	3.50
	12:50P	22.0		9.30	100	9.30	5.40	3.90	3.90
	4:55P	22.0		13.10	100	13.10	5.70	7.40	7.40
	9.05P	22.0		11.25	100	11.25	4.80	6.45	6.45
8-25	1:05A	21.0		8.55	100	8.55	2.95	5.60	5.60
	5:00A	21.0		7.00	100	7.00	1.95	5.05	5.05

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 6 - Tittabawassee River at Smith's Crossing Rd. Br. - 1/4 nearest Mapleton

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD$_5$ mg/l
8-23	9:40A	27.0		5.75	100	5.75	0.70	5.05	5.05
					50	7.60	4.30	3.30	6.60
	1:42P	28.0	7.30	5.65	100	5.65	1.30	4.35	4.35
					50	7.20	4.55	2.65	5.30
	5:20P	28.0	7.40	5.70	100	5.70	2.15	3.55	3.55
					50	7.25	4.20	3.05	6.10
	9:45P	28.0	7.35	4.15	100	4.15	2.20	1.95	1.95
					50	6.30	4.75	1.55	3.10
8-24	1:50A	26.0	7.20	5.20	100	5.20	2.55	2.65	2.65
					50	7.35	4.10	3.25	6.50
	5:50A	20.0	7.30	4.70	100	4.70	0.40	4.30	4.30
					50	7.10	3.77	3.33	6.66
	9:10A	27.0	7.30	5.00	100	5.00	0	5.00	5.00
					50	6.95	3.92	3.03	6.06
	1:15P	29.0	7.40	4.95	100	4.95	0.75	4.20	4.20
					50	7.20	3.90	3.30	6.60
	5:15P	27.0	7.45	5.00	100	5.00	1.65	3.35	3.35
					50	6.80	4.65	2.15	4.30
	9:20P	27.0	7.40	4.55	100	4.55	1.35	3.20	3.20
					50	6.85	4.60	2.25	4.50
8-25	1:20A	26.0	7.35	4.75	100	4.75	1.25	3.50	3.50
					50	7.00	4.50	2.50	5.00
	5:15A	26.0	7.35	4.50	100	4.50	0.70	3.80	3.80
					50	7.15	4.35	2.80	5.60

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 7 - Tittabawassee River at Smith's Crossing Rd. Bridge - Center

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D O	Depl.	BOD_5 mg/l
8-23	9:50A	27		5.65	100	5.65	0.85	4.80	4.80
					50	7.63	4.10	3.53	7.06
	1:50P	28	7.55	5.80	100	5.80	1.75	4.05	4.05
					50	7.20	4.70	2.50	5.00
	5:30P	28	7.40	5.45	100	5.45	2.70	2.75	2.75
					50	7.20	4.35	2.85	5.70
	9:55P	27	7.40	4.20	100	4.20	2.50	1.70	1.70
					50	6.25	4.55	1.70	3.40
8-24	2:05A	26	7.35	5.40	100	5.40	2.55	2.85	2.85
					50	7.45	4.05	3.40	6.80
	6:00A	20	7.30	4.90	100	4.90	0.25	4.65	4.65
					50	7.30	3.90	3.40	6.80
	9:20A	27	7.20	5.05	100	5.05	0	5.05	5.05
					50	7.00	4.00	3.00	6.00
	1:25P	29	7.30	4.75	100	4.75	0.10	4.65	4.65
					50	6.65	3.90	2.75	5.50
	5:30P	27	7.20	5.05	100	5.05	1.90	3.15	3.15
					50	6.80	4.50	2.30	4.60
	9:30P	27	7.40	4.95	100	4.95	2.60	2.35	2.35
					50	7.05	4.85	2.20	4.40
8-25	1:30A	26	7.40	4.90	100	4.90	1.55	3.35	3.35
					50	7.30	4.10	3.20	6.40
	5:25A	26	7.30	5.10	100	5.10	1.10	4.00	4.00
					50	7.30	4.45	2.85	5.70

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 8 - Tittabawassee River at Smith's Crossing Rd. Bridge - 1/4 Farthest from Mapleton

Date	Time of Collection	Temp$^\circ$C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD$_5$ mg/l
8-23	10:00A	27		5.75	100	5.75	0.60	5.15	5.15
					50	7.25	3.85	3.40	6.80
	2:00P	28	7.55	6.50	100	6.50	2.30	4.20	4.20
					50	7.35	4.95	2.40	4.80
	5:45P	28	7.30	5.30	100	5.30	2.00	3.30	3.30
					50	7.00	4.30	2.70	5.40
	10:10P	27	7.30	4.00	100	4.00	1.70	2.30	2.30
					50	6.10	4.30	1.80	3.60
8-24	2:10A	25	7.30	5.00	100	5.00	1.85	3.15	3.15
					50	7.25	4.85	2.40	4.80
	6:10A	19	7.40	4.70	100	4.70	0.90	3.80	3.80
					50	7.20	4.20	3.00	6.00
	9:30A	27	7.30	5.25	100	5.25	0	5.25	5.25
					50	7.15	3.90	3.25	6.50
	1:35P	29	7.50	6.80	100	6.80	3.10	3.70	3.70
					50	7.50	4.85	2.65	5.30
	5:45P	27	7.40	5.40	100	5.40	2.20	3.20	3.20
					50	7.00	4.80	2.20	4.40
	9:40P	28	7.20	4.20	100	4.20	1.25	3.95	3.95
					50	6.85	4.30	2.55	5.10
8-25	1:40A	26	7.40	4.20	100	4.20	1.40	2.80	2.80
					50	7.05	4.70	2.35	4.70
	5:35A	26	7.50	4.75	100	4.75	0.80	3.95	3.95
					50	7.25	4.40	2.85	5.70

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 9 - Tittabawassee River at Freeland Rd. Bridge - Center

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/l
8-23	10:15A	26	7.50	4.95	50	7.15	5.05	2.10	4.20
					25	7.80	6.45	1.35	5.40
	2:20P	26	7.60	5.05	50	6.85	4.80	2.05	4.10
					25	7.45	6.20	1.25	5.00
	6:10P	25	7.45	4.90	50	7.05	4.50	2.55	5.10
					25	7.50	5.80	1.70	6.80
	10:30P	25	7.40	3.00	50	6.00	4.15	1.85	3.70
					25	6.65	5.95	0.70	2.80
8-24	2:30A	24	7.40	3.90	50	6.85	4.60	2.25	4.50
					25	7.50	6.05	1.45	5.80
	6:25A	19	7.40	3.55	50	6.80	4.40	2.40	4.80
					25	7.30	5.83	1.47	5.88
	9:55A	26	7.25	4.30	50	6.75	4.90	1.85	3.70
					25	7.60	6.20	1.40	5.60
	1:55P	27	7.35	4.50	50	6.80	4.65	2.15	4.30
					25	7.45	5.90	1.55	6.20
	6:05P	26	7.40	4.70	50	6.90	4.60	3.30	6.60
					25	7.55	5.80	1.35	5.40
	10:00P	27	7.45	4.00	50	6.90	4.35	2.55	5.10
					25	7.65	6.00	1.65	6.60
8-25	2:05A	26	7.30	3.75	50	6.85	4.85	2.00	4.00
					25	7.50	5.95	1.55	6.20
	5:55A	26	7.25	3.10	50	7.05	4.70	2.35	4.70
					25	7.70	6.10	1.60	6.40

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 10 - Tittabawassee River West of M-47, 4 Miles South of Freeland Opposite D and B Trailer Sales Sign - by Wading about 20 Yards from Shore

Date	Time of Collection	Temp °C.	pH	D.O. mg/1	BOD mg/1				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/1
8-23	10:50A	24.0	7.60	5.05	50	7.20	5.30	1.90	3.80
					25	7.95	6.20	1.75	7.00
	4:45P	23.5	7.50	5.45	50	7.10	5.50	1.60	3.20
					25	7.50	6.25	1.25	5.00
8-24	9:50A	25.0	7.40	3.90	50	6.70	4.82	1.88	3.76
					25	7.05	6.20	0.85	3.40
	3:15P	26.5	7.60	5.30	50	7.00	5.35	1.65	3.30
					25	7.65	6.20	1.45	5.80

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 11 - Tittabawassee River at State Rd. Bridge in Saginaw (M-47) - Center

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/l
8-23	10:35A	26	7.75	5.80	50	7.50	6.00	1.50	3.00
					25	8.00	7.00	1.00	4.00
	2:45P	24	7.80	6.00	50	7.15	5.80	1.35	2.70
					25	7.50	6.85	0.65	2.60
	6:50P	23	7.60	5.25	50	7.25	5.80	1.45	2.90
					25	7.70	6.20	1.50	6.00
	10:55P	23	7.50	3.60	50	6.00	5.45	0.55	1.10
					25	7.10	6.50	0.60	2.40
8-24	2:50A	—	7.45	4.40	50	7.40	5.35	2.05	4.10
					25	7.40	6.15	1.25	5.00
	6:40A	22	7.60	3.95	50	6.85	5.50	1.35	2.70
					25	7.50	6.60	0.90	3.60
	10:30A	25	7.50	3.90	50	6.75	5.10	1.65	3.30
					25	7.50	6.20	1.30	5.20
	2:25P	23	7.60	3.80	50	6.65	5.10	1.55	3.10
					25	7.25	6.30	0.95	3.80
	6:35P	26	7.70	5.40	50	7.10	5.40	1.70	3.40
					25	7.65	6.20	1.45	5.80
	10:25P	25	7.65	4.80	50	7.15	5.20	1.95	3.90
					25	7.85	6.30	1.55	6.20
8-25	2:25A	24	7.50	4.45	50	6.90	5.20	1.70	3.40
					25	7.60	6.15	1.45	5.80
	6:10A	24	7.35	3.80	50	7.10	5.15	1.95	3.90
					25	7.75	6.20	1.55	6.20

TITTABAWASSEE RIVER SURVEY DATA

August 23 to 25, 1961

Station 12 - Tittabawassee River at Center Rd. Bridge in Saginaw - Center

Date	Time of Collection	Temp° C.	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/l
8-23	10:50A	24		5.95	100	5.95	3.60	2.35	2.35
					50	7.55	5.95	1.60	3.20
	3:00P	23	8.0	6.30	100	7.20	5.75	1.45	1.45
					50	7.65	6.80	0.85	1.70
	7:05P	23	7.95	6.10	100	6.10	4.30	1.80	1.80
					50	7.10	5.70	1.40	2.80
	11:25P	22	8.10	5.65	100	5.65	3.40	2.25	2.25
					50	6.95	5.15	1.80	3.60
8-24	3:15A	—	8.00	6.50	100	6.50	3.35	3.15	3.15
					50	7.70	5.35	2.35	4.70
	7:05A	23	7.70	4.60	100	4.60	3.35	1.25	1.25
					50	7.10	5.40	1.70	3.40
	10:45P	25	7.70	4.95	100	4.95	3.20	1.75	1.75
					50	7.35	5.70	1.65	3.30
	2:40P	23	7.60	4.10	100	4.10	3.35	0.75	0.75
					50	7.05	5.50	1.55	3.10
	6:50P	27	7.30	4.65	100	4.65	3.00	1.65	1.65
					50	7.05	5.60	1.45	2.90
	10:45P	24	7.70	4.40	100	4.40	2.75	1.65	1.65
					50	7.25	5.45	1.80	3.60
8-25	2:40A	23	7.60	4.85	100	4.85	2.75	2.10	2.10
					50	7.30	5.50	1.80	3.60
	6:25A	23	7.50	8.20	100	8.20	1.50	6.70	6.70
					50	7.10	4.80	2.30	4.60

TITTABAWASSEE RIVER SURVEY DATA

Special Sampling during August 23 to 25, 1961 Survey

Date	Time of Collection	Temp °C	pH	D.O. mg/l	BOD mg/l				
					% Conc.	Initial D.O.	Final D.O.	Depl.	BOD_5 mg/l
Dow 60" Drain - Sampled from Sewer Manhole before Discharge to River									
8-23	3:30P	34.0	8.00	5.70	50	7.10	0.70	6.40	12.80
					25	7.40	4.70	2.70	10.80
Bullock Creek - Sampled before Discharge to River									
8-23	3:45P		7.90		50	8.75	6.85	1.90	3.80
					25	8.20	6.82	1.38	5.52
Tittabawassee River Immediately below Dow Treatment Plant Outfall in Effluent Stream									
8-24	12:45P	32.5	6.70	5.15	100	5.15	0.40	4.75	4.75
					50	6.70	3.30	3.40	6.80
Tittabawassee River Opposite Dow Treatment Plant Outfall in Flow from Upstream									
8-24	12:50P	31.75	7.75	6.45	100	6.45	3.40	3.05	3.05
					50	7.30	4.50	2.80	5.60
Tittabawassee River halfway between Dow Treatment Plant Outfall and Smith's Crossing Br.									
8-24	1:25P	30.0	7.25	5.45	100	5.45	0.80	4.65	4.65
					50	6.80	4.25	2.55	5.10
Lingle Drain above 84" Drain									
8-24	6:15P	27.0	7.35	2.80	50	6.35	4.10	2.25	4.50
					25	7.10	5.75	1.35	5.40
					10	7.60	6.80	0.80	8.00
84" Drain before Discharge into Lingle Drain									
8-24	6:30P	28.5	7.75	5.75	50	7.40	4.70	2.70	5.40
					25	7.75	6.10	1.65	6.60

BOD RATE SUMMARIES

River **Tittabawassee** Station **Currie St. Bridge**

Number (1)	Date 1961 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
1	6-20	11:33A	692	19.5	20	6.38	6.61		12	1.67	-	1.92	.16
18	6-29	9:25A	344	25.5	20	7.29	6.72		9	1.27	-	1.89	.04
23	7-6	10:15A	446	23.0	20	6.46	6.65		10	1.76	-	2.52	<.01
37	7-13	8:15A	308	29.0	20	6.55	6.76		10	1.08	-	1.39	.08
45	7-20	8:15A	367	24.0	20	6.38	6.75		10	3.02	-	4.86	.08
57	8-3	10:20A	761	24.0	20	7.56	12.68		11	2.47	3.89	4.74	.04
59	8-9	8:30A	623	24.0	20	6.95	6.82		11	3.85	-	5.37	<.01
69	8-24	-	238	22.0	20	-	92.24		8	1.77	2.72	9.58	.02

BOD RATE SUMMARIES

River Tittabawassee Station Benson St. Bridge

Number (1)	Date 1960-1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
6	8-3	-	568	24.5	20	-	41.81		5	4.43	6.48	10.25	.07
	2-23	-	2560	4.0	20	-	6.55		8	3.02	-	3.75	.07
74	10-10	9:30A	985	16.5	20	-	13.67	100% river	10	2.63	3.84	5.40	.10
74	10-10	9:30A	985	16.5	20	-	13.67	50% river 50% dil H_2O	10	3.63	5.19	8.48	.02
90	12-18	9:30A	897	0.5	20	11.50	14.62		12	1.65	3.30	4.45	.02
94	1-29	10:30A	636	0.0	20	9.25	13.94		11	1.53	2.93	4.10	<.01
110	4-9	9:40A	2220	7.0	20	9.80	13.75		11	1.45	2.79	3.20	.05
118	5-7	10:15A	5220	14.5	20	7.75	14.67		11	1.94	3.00	4.15	.08
119	5-7	10:30A	5220	14.5	20	7.60	14.67		11	1.88	3.23	4.60	<.01
130	6-18	10:00A	607	23.0	20	5.50	12.85		11	3.49	5.40	6.35	.16
141	7-23	7:45A	491	21.0	20	5.70	13.68		11	4.00	5.78	7.85	.06

BOD RATE SUMMARIES

River Tittabawassee

Station Midland WTP

Number (1)	Date 1961 (2)	Time Collected (3)	Runoff cfs (40	Temp. °C. (5)	Incubation Temp. °C. (6)	Effluent D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 1st 5 Days (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
82	11-9	11:00A	920	-	20	2.20	12.81	5% waste	8	80.8	99.8	120.0	.16
82	11-9	11:00A	920	-	20	2.20	12.81	10% waste	8	74.71	102.0	121.0	.20

BOD RATE SUMMARIES

River Tittabawassee

Station Dow Final Effluent

Number	Date 1960-1961	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1 1st 5 Days	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
A'	7-12	-	603	34	20	-	26.59	normal	8	4.75	8.03	15.91	.05
C'	7-12	-	603	34	20	-	12.65	20% waste 80% dil H_2O	3	8.53	13.03	14.00	<.01
9	8-3	9:00A	568	-	20	-	28.61		5	5.41	7.60	13.15	<.01
10	8-3	9:00A	568	-	20	-	33.60		5	4.66	7.42	13.00	.03
7	8-3	9:00A	568	-	20	-	28.60	50% river H_2O 50% waste	5	4.87	8.22	13.65	.07
8	8-3	9:00	568	-	20	-	28.59	50% river H_2O 50% waste	5	4.45	5.73	12.30	.02
	2-23	8:00A	2560	-	20	-	6.56		7	8.33	-	10.60	<.01
	2-23	-	2560	-	20	-	6.57		7	7.08	-	9.12	<.01
	5-4	8:00A	1860	15	20	3.60	6.70	stirred nonfiltered	10	15.00	-	18.10	.07
	5-4	8:00A	1860	15	20	3.60	6.70	stirred filtered	10	9.09	-	10.80	.09
	5-4	8:00A	1860	15	20	3.60	6.70	nonstirred nonfiltered	10	9.72	-	11.25	.14
17	6-29	8:50A	344	32	20	1.62	6.72		9	5.79	-	7.82	.05

BOD RATE SUMMARIES

River Tittabawassee

Station Dow Final Effluent

Number	Date 1961	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/l	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD$_5$ mg/l	BOD$_{10}$ mg/l 1st 5 Days	BOD mg/l Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
22	7-6	9:30A	446	-	20	3.94	13.63	stirred	11	9.64	15.54	19.61	<.01
22	7-6	9:30A	446	-	20	3.94	13.63	nonstirred	11	6.23	10.96	13.88	<.01
22	7-6	9:30A	446	-	20	3.94	5.94	100, 75, 50 and 25%	16	12.60	-	13.72	<.01
36	7-13	9:00A	308	-	20	0.71	6.76	stirred	10	5.04	-	6.93	.06
36	7-13	9:00A	308	-	20	0.71	6.76	nonstirred	11	5.14	-	5.67	.07
36	7-13	9:00A	308	-	33	0.71	6.76	hot	12	10.19	-	12.53	.03
46	7-20	9:00A	367	33	20	3.64	6.76		10	7.53	-	9.51	<.01
49	7-26	9:20A	727	29	20	4.53	6.70	normal	12	29.56	-	34.97	<.01
49	7-26	9:20A	727	29	33	4.53	6.70	hot	11	12.34	-	18.80	<.01
49	7-26	9:20A	727	29	10	4.53	6.70	cold	11	1.44	-	2.27	.03
58	8-3	10:35A	761	29	20	3.98	5.98		11	6.19	-	6.65	<.01
60	8-9	10:45A	623	33	20	4.43	6.82	normal	11	2.67	-	3.97	.02
60	8-9	10:45A	623	33	33	4.43	6.82	hot	12	7.89	-	10.23	<.01
67	8-24	-	238	-	20	-	52.47		8	3.65	6.21	33.67	<.01
68	8-24	-	238	-	20	-	43.60		8	3.22	6.07	26.61	<.01
73	10-10	9:30A	985	28	20	3.22	13.67	100%	9	5.54	9.54	11.34	<.01
73	10-10	9:30A	985	28	20	3.22	13.67	50% waste 50% dil H_2O	9	7.18	10.66	13.50	<.01

BOD RATE SUMMARIES

River Tittabawassee

Station Dow Final Effluent

Number	Date 1961-1962	Time Collected	Runoff cfs	Temp. °C.	Incubation Temp. °C.	Effluent D.O. mg/l	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD$_5$ mg/l	BOD$_{10}$ mg/l 1st 5 Days	BOD mg/l Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(40	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
81	11-9	10:15A	920	25	20	4.20	12.81		8	6.34	8.92	10.65	<.01
89	12-18	9:10A	897	28	20	4.60	14.62		12	5.81	11.12	16.05	<.01
93	1-29	11:20A	636	15	20	4.75	13.66		11	6.42	13.43	15.95	.03
101	3-5	9:00A	596	15	20	3.50	30.59		11	10.73	25.09	42.15	.04
109	4-9	9:50A	2220	15	20	3.90	27.91		11	6.58	18.69	31.95	<.01
117	5-7	10:00A	5220	23	20	4.55	14.67		11	9.15	16.97	22.25	<.01
131	6-18	9:45A	607	28	20	5.15	13.71		11	54.64	82.77	97.20	.02
136	7-2	10:00A	450	28	20	2.70	13.67		10	3.95	7.65	9.20	<.01
142	7-23	8:30A	491	30	20	4.10	13.68	routine rate	11	2.67	4.42	5.55	<.01
142	7-23	8:30A	491	30	20	4.10	13.68	dil.meth.	12	2.96	4.90	6.80	<.01
142	7-23	8:30A	491	30	20	4.10	13.68	settled	11	2.20	3.53	4.15	<.01
142	7-23	8:30A	491	30	20	4.10	13.68	filtered	11	2.16	3.45	4.15	<.01
148	8-15	6:30A	258	30	20	2.50	148.53		9	2.26	3.84	91.52	.05

BOD RATE SUMMARIES

River **Tittabawassee** Station **Smith's Crossing**

Number	Date 1960-1961	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
B'	7-12	-	603	32	20	-	18.84		8	3.81	5.99	12.25	.09
5	8-3	-	568	28.5	20	-	25.84		6	2.96	5.03	10.85	.03
-	2-23	-	2560	6.5	20	-	6.55		7	4.17	-	5.23	.10
2	6-20	11:50A	692	24.5	20	6.48	6.62	nonstirred	12	3.11	-	3.83	.08
2	6-20	11:50A	692	24.5	20	6.48	6.62	stirred	12	7.35	-	9.08	.05
16	6-29	8:15A	344	28.5	20	5.77	6.71	nonstirred	9	3.67	-	4.38	.02
16	6-29	8:15A	344	28.5	20	5.77	6.71	stirred	9	5.26	-	6.72	.07
21	7-6	9:05A	446	27.5	20	5.86	6.65	nonstirred	11	3.27	-	3.95	<.01
21	7-6	9:05A	446	27.5	20	5.86	6.65	stirred	11	5.32	-	6.20	.07
35	7-13	9:20A	308	-	20	5.14	6.76	normal	10	4.15	-	5.31	<.01
35	7-13	9:20A	308	-	33	5.14	6.76	hot	11	8.46	-	10.59	.10
44	7-20	7:50A	367	30.5	20	5.47	6.75		10	4.56	-	5.47	.11
48	7-26	8:30A	727	27	20	6.45	6.70	normal	12	17.46	-	17.67	<.01
48	7-26	8:30A	727	27	33	6.45	6.70	hot	11	6.72	-	8.75	.12
48	7-26	8:30A	727	27	10	6.45	6.70	cold	11	.83	-	1.20	.20
56	8-3	9:50A	761	27	20	6.40	12.68	normal	11	3.79	6.46	7.44	.05
56	8-3	9:50A	761	27	20	6.40	3.70	lights	-	-	-	-11.65	-
56	8-3	9:50A	761	27	20	6.40	3.70	nonaerated	-	-	-	3.22	-

BOD RATE SUMMARIES

River Tittabawassee Station Smith's Crossing

Number	Date 1961-1962	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
61	8-9	12:30P	623	30	20	6.05	6.82	normal	11	3.16	-	4.09	.07
61	8-9	12:30P	623	30	33	6.05	6.82	hot	12	6.61	-	7.95	.13
70	8-24	-	238	28.5	20	-	92.24	normal	8	3.12	4.84	23.43	.07
70	8-24	-	238	28.5	33	-	82.46	hot	8	7.01	10.16	31.02	<.01
75	10-10	9:30A	985	21.5	20	7.36	13.67	100% waste	10	2.86	4.23	5.33	.10
75	10-10	9:30A	985	21.5	20	7.36	13.67	50% waste 50% dil.	10	4.03	5.08	[illegible]	.05
83	11-9	11:45A	920	-	20	10.10	12.81		8	3.08	4.71	5.00	.10
91	12-18	10:00A	897	4	20	11.25	14.62	normal	12	1.55	3.30	4.55	<.01
91	12-18	10:00A	897	4	30	11.25	14.62	hot	12	1.99	4.66	6.95	.07
91	12-18	10:00A	897	4	4	11.25	14.62	cold	12	- .13	.18	.50	-
95	1-29	12 noon	636	3.5	20	9.80	13.94	normal	11	4.46	6.05	14.10	<.01
95	1-29	12 noon	636	3.5	30	9.80	13.94	hot	11	6.17	10.87	14.20	.11
95	1-29	12 noon	636	3.5	3.5	9.80	13.94	cold	11	.53	1.88	2.45	<.01
103	3-5	10:45A	596	4	20	9.50	13.64	normal	10	5.71	7.90	9.15	<.01
103	3-5	10:45A	596	4	30	9.50	13.64	hot	9	7.46	14.18	15.50	.10
103	3-5	10:45A	596	4	4	9.50	13.64	cold	10	.73	2.72	3.05	<.01
111	4-9	10:15A	2220	8	20	9.40	13.75	normal	11	2.31	4.67	7.25	.01
111	4-9	10:15A	2220	8	30	9.40	13.75	hot	11	4.49	7.66	10.10	.03

BOD RATE SUMMARIES

River Tittabawassee

Station Smith's Crossing

Number (1)	Date 1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
111	4-9	10:15A	2220	8	8	9.40	13.75	cold	11	.72	1.56	2.20	<.01
120	5-7	11:15A	5220	15.5	20	7.10	14.67	normal	11	2.10	4.04	6.80	.01
120	5-7	11:15A	5220	15.5	30	7.10	14.67	hot	11	4.13	9.54	10.75	<.01
120	5-7	11:15A	5220	15.5	15.5	7.10	14.67	cold	11	1.24	2.10	5.35	<.01
132	6-18	10:45A	607	28	20	4.95	13.71	normal	11	16.97	22.02	26.30	.18
132	6-18	10:45A	607	28	30	4.95	13.71	hot	11	21.27	31.31	35.55	.24
135	7-2	10:30A	450	29	20	5.20	13.67		10	3.47	5.35	6.40	.02
135	7-2	10:30A	450	29	20	5.20	13.67		10	3.41	5.15	6.45	<.01
135	7-2	10:30A	450	29 -	20	5.20	13.67		10	3.45	5.68	6.70	.03
135	7-2	10:30A	450	29	20	5.30	13.67		10	3.08	5.25	6.45	<.01
135	7-2	10:30A	450	29	20	5.35	13.67		10	3.22	5.02	6.15	<.01
143	7-23	9:00A	491	26	20	5.40	13.68	routine rate	11	2.00	3.50	4.60	<.01
143	7-23	9:00A	491	26	20	5.40	13.68	dilution	11	2.00	4.40	6.50	<.01
143	7-23	9:00A	491	26	20	5.40	13.68	settled	11	2.05	3.97	5.25	.04
143	7-23	9:00A	491	26	20	5.40	13.68	filtered	11	2.30	4.13	4.85	<.01
149	8-15	7:45A	258	29	20	6.20	164.29		9	2.12	3.66	35.35	.08

BOD RATE SUMMARIES

River Tittabawassee Station Freeland Bridge

Number	Date 1960-1962	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	8-3	-	568	28	20	-	25.84		6	3.15	4.95	11.5	.09
	2-23	-	2560	7	20	-	6.56		7	5.13	-	5.37	.02
3	6-20	1:59P	692	-	20	6.18	6.62		12	2.56	-	3.22	.19
20	7-6	8:20A	446	25.5	20	5.25	7.61		11	3.60	-	4.18	.07
43	7-20	7:25A	367	29	20	4.05	6.75		10	4.96	-	5.78	.22
47	7-26	7:45A	727	25.75	20	5.80	6.70	normal	12	24.36	-	25.88	<.01
47	7-26	7:45A	727	25.75	33	5.80	6.70	hot	10	5.31	-	6.65	.24
47	7-26	7:45A	727	25.75	10	5.80	6.70	cold	11	1.41	-	1.97	<.01
55	8-3	9:25A	761	26	20	6.00	12.67		12	3.93	-	7.46	.05
62	8-9	1:30P	623	29	20	7.05	6.82		11	3.29	-	4.34	.07
71	8-24	-	238	26	20	-	107.23		8	2.56	5.15	22.71	<.01
76	10-10	9:30A	985	21	20	7.56	13.67	100%	10	2.13	2.97	3.68	.03
76	10-10	9:30A	985	21	20	7.56	13.67	{50% waste {50% dil.	10	2.58	4.04	4.84	.03
76	10-10	9:30A	985	21	20	7.56	13.67	{25% waste {75% dil.	10	4.31	5.04	5.04	.06
84	11-9	12:15P	920	-	20	10.4	12.81		8	2.45	3.89	4.15	.06
92	12-18	10:30A	897	4.0	20	11.10	14.62		12	2.85	4.50	6.50	.11
96	1-29	12:20P	636	2.5	20	10.00	13.94		11	4.87	6.86	11.60	.01

BOD RATE SUMMARIES

River Tittabawassee   Station Freeland Bridge

Number (1)	Date 1962 (2)	Time Collected (3)	Runoff cfs (4)	River Temp. °C. (5)	Incubation Temp. °C. (6)	River D.O. mg/1 (7)	Rate Duration Days (8)	Rate Conditions (9)	No. Obs. 1st 5 Days (10)	BOD_5 mg/1 (11)	BOD_{10} mg/1 (12)	BOD mg/1 Final (13)	K_1 for 1st 5 Days (14)
104	3-5	11:30A	596	3	20	9.55	13.64		10	4.57	6.25	8.05	<.01
112	4-9	10:30A	2220	9	20	9.45	13.75		11	3.18	5.01	6.75	.06
121	5-7	12 noon	5220	15.5	20	7.10	14.67		11	2.26	5.80	7.90	<.01
133	6-18	11:30A	607	26	20	5.30	12.85		11	3.08	5.29	7.20	.08
144	7-23	9:30A	491	24.5	20	4.80	13.68		11	2.52	4.23	5.50	<.01
150	8-15	7:10P	258	27.5	20	6.30	13.29		9	1.70	2.91	4.85	.07

BOD RATE SUMMARIES

River Tittabawassee

Station State Street Bridge Saginaw

Number	Date 1962	Time Collected	Runoff cfs	River Temp. °C.	Incubation Temp. °C.	River D.O. mg/1	Rate Duration Days	Rate Conditions	No. Obs. 1st 5 Days	BOD_5 mg/1	BOD_{10} mg/1	BOD mg/1 Final	K_1 for 1st 5 Days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
102	3-5	1:00P	596	3	20	9.55	13.64		10	3.62	5.61	5.90	< .01

APPENDIX III EXPLANATION OF K-RATE PROGRAM
Using the Procedures of Theriault

EXPLANATION OF K-RATE PROGRAM

Using the Procedures of Theriault(1)

MODEL AND INPUT DATA:

We suppose that the oxygen demand X at time T is $X = L(1 - 10^{-K\cdot T})$. From a set X(1) . . . X(N) of X's and a corresponding set T(1) . . . T(N) of T's it is desired to estimate K.

The model equation $X = L(1 - 10^{-K\cdot T})$ is not linear in K. By choosing a provisional estimate K and adding a correction factor H, we may say that the true "K" is K + H. Then if H is sufficiently small an approximation to the above model is

$$X = L\cdot(1 - 10^{-K\cdot T}) + L\cdot H\cdot(C\cdot T\cdot 10^{-K\cdot T})$$

where

$$C = \log_e\ 10 = 2.30259\ .\ .\ .$$

If we set

$$B1 = L, \qquad B2 = L\cdot H$$

$$F1 = (1 - 10^{-K\cdot T}), \qquad F2 = (C\cdot T\cdot 10^{-K\cdot T}),$$

then

$$X = B1\cdot F1 + B2\cdot F2$$

or in general

$$X(I) = B1\cdot F1(I) + B2\cdot F2(I), \qquad 1 \leq I \leq N,$$

where now

$$F1(I) = (1 - 10^{-K\cdot T(I)})$$

and

$$F2(I) = (C\cdot T(I)\cdot 10^{-K\cdot T(I)}).$$

Now we find estimates of B1 = L and B2 = L·H. Then our estimate of H is B2/B1. And our improved estimate of K is K + H. This procedure may be repeated by choosing K + H as the new provisional estimate. The input to the computer is X(1). . . X(N) and T(1) . . . T(N).

ALGORITHM FOR OBTAINING K-RATE:

The following set of equations is an algorithm for obtaining K and various estimates of variances (which will be explained later). Items in parentheses are remarks.

```
START   Execute zero.  (SX, SXX, RESSS)
                  (this sets these three quantities all equal to
                  zero.  These quantities are defined later).
        Read  N,K
                  (N = no. points used,  K = provisional estimate
                  of K)
        Read  X(1) . . . X(N)
        Read  T(1) . . . T(N)
        Print results  T(1) . . . T(N)
        Print results  X(1) . . . X(N)
                  (the T's and X's are printed out, so that their
                  correctness may be checked).
        Through PP, for P = N, 1, P.G.N.
                  (this is an iterative statement and it means;
                  do the following statements, up to and including
                  the statement labeled "PP", over and over again,
                  with an initial value of P = 1, incrementing P
                  by +1 each time the statement "PP" is reached,
                  and halting the iterative process when "PP" is
                  reached when P = N.  Notice here that P is
                  initially set at N so that only one iteration
                  is made.  P could be initially set at any
                  number from 4 to N, and estimates of K will
                  successively be obtained using P points, P + 1
                  points, . . ., N points).
        J = 0
                  (J is used to count the number of iterations
                  that are needed to get H "sufficiently small".
                  (H <.001·K).  J is initially set at zero).
OVER    Execute zero.  (F11, F22, F12, F1X, F2X)
                  (This sets the five quantities within the
                  parentheses each equal to zero.  This statement
                  is labeled with the statement label "Over"
                  because this statement will be referred to later
                  in the program).
```

```
Through F, for I = 1, 1, I.G.P.
```

(Another iterative statement. Its significance will be explained after the statement whose label is "F").

```
    E = Exp.   (-2.3026 * K * T(I))
F1(I) = 1.-E
F2(I) = 2.3026 * T(I) * E
```

(The F1(I) and F2(I) previously mentioned are computed).

```
  F11 = F11 + F1(I) * F1(I)
```

(When the iteration has been completed, F11 will equal $\sum_{I=1}^{P} F1(I) \cdot F1(I)$).

```
  F22 = F22 + F2(I) * F2(I)
```

(when the iteration has been completed, F22 will equal $\sum_{I=1}^{P} F2(I) \cdot F2(I)$).

```
  F12 = F12 + F1(I) * F2(I)
```

(When the iteration has been completed F12 will equal $\sum_{I=1}^{P} F1(I) \cdot F2(I)$).

```
  F1X = F1X + F1(I) * X(I)
```

(When the iteration has been completed, F1X will equal $\sum_{I=1}^{P} F1(I) \cdot X(I)$).

```
F     F2X = F2X + F2(I) * X(I)
```

(This is the last statement of the "F" iteration. F2X will equal $\sum_{I=1}^{P} F2(I) \cdot X(I)$).

All the information needed to compute H from the X's and T's has now been incorporated into the five sums, F11, F22, F12, F1X, F2X

```
Print results F11, F12, F22, F1X, F2X
```

(These five quantities are printed out so they may be inspected. In the terminology of the paper on the Reed-Theriault method we have for

$\gamma = 2.3026$: $\quad \gamma \cdot C = \gamma \cdot \Sigma f_1 f_2 = f12$,

$A = \Sigma f_1^2 = F11$, $\quad F = \Sigma f_1 X = F1X$,

$\gamma^2 B = \gamma^2 \Sigma f_2^2 = F22$, $\quad \gamma \cdot H = \gamma \cdot \Sigma f_2 X = F2X$).

```
J = J + 1
```

(The "counter" J is increased by +1 each time the five quantities F11, F22, F12, F1X, and F2X are computed).

```
DET = F11 * F22 - F12 * F12,
```

(DET is a nuisance parameter).

```
B1 = (F22 * F1X - F12 * F2X)/DET,
```

(B1 is the estimate of L).

```
B2 = (F11 * F2X - F12 * F1X)/DET,
```

(B2 is the estimate of L·H).

```
H = B2/B1
K = K + H
```

(the K on the left-hand side is the improved estimate).

```
Whenever  .ABS.H.G..001 * K.AND.J.L.6,  Transfer to Over
```

(this statement instructs the computer to go back to the statement labeled "Over" and recalculate F11, F22, F12, F1X, F2X, B1, B2, H, and K if $|H| < .001 \cdot K$ and the number J of iterations is less than 6. When the number of iterations reaches 6 and $|H| < .001 \cdot K$, then the next statement is executed, for it appears that H is not converging to zero with respect to K. Up to this point, the computation of K is essentially completed. The following statements compute variance estimates for various quantities).

```
Execute zero. (SX, SXX, RESSS)
```

(These 3 quantities are set equal to zero).

```
Through SS, for I = 1,1,I.G.P
```

(An iterative statement. This iteration is used to compute

$$SX = \sum_{I=1}^{P} X(I),$$

$$SXX = \sum_{I=1}^{P} S(I) \cdot X(I), \text{ and}$$

$$RESSS = \sum_{I=1}^{P} ((X(I) - B1 \cdot F1(I) - B2 \cdot F2(I))^2)$$

```
           SXX =  SXX + X(I) * X(I)
            SX = SX + X(I)
SS       RESSS = RESSS + (X(I)-B1*F1(I)-B2*F2(I). P·2
         TOTSS = SXX - SX * SX/P
                   (Here TOTSS = $\sum_{I=1}^{P} (X(I) - \overline{X})^2$).
         REGSS = TOTSS - RESSS
                   (RESSS is the total sum of squares about the
                   fitted regression curve.  The smaller RESSS is
                   with respect to TOTSS, the better the data fit
                   the model.  REGSS may be considered as that
                   portion of the TOTSS which is "explainable" by
                   the model.  The larger REGSS is with respect
                   to RESSS, the better the data fit the model).
           VXT = RESSS/(P-3)
                   (VXT is an estimate of the variance of X(I),
                   for a given T(I), about the fitted regression
                   curve).
            FA = VXT/DET
                   (FA is a nuisance parameter).
           VB1 = F22 * FA
                   (VB1 is an estimate of the variance of B1 = L).
           VB2 = F11 * FA
                   (VB2 is an estimate of the variance of B2 = L·H).
          VB12 = -1. * F12 * FA
                   (VB12 is an estimate of the covariance between
                   B1 = L·H and B2 = L).
            VK = (VB2 - 2*H*VB12 + H*H * VB1)/(B1 * B1)
                   (VK is an estimate of the variance of K).
        VCHECK = VB1/(B1 * B1)
                   (VCHECK is a "check" on the estimated variance
                   VK of K.  For a good estimate of VK, VCHECK
                   should be less than .05).
         Print results P, K, B1, B2, VCHECK, H, J
PP       Print results TOTSS, RESSS, REGSS, VXT, VK, VB1, VB2, VB12
         Transfer to start
         End of program
```

REFERENCES

1. Theriault, E. J., "The Oxygen Demand of Polluted Waters," Public Health Bulletin, No. 173, USPHS, Washington, D.C. (1927).

APPENDIX IV EXPLANATION OF OXYGEN PROFILE PROGRAM

as Used in
Programming River Dissolved Oxygen
Calculations
by
Gannon and Downs

EXPLANATION OF OXYGEN PROFILE PROGRAM
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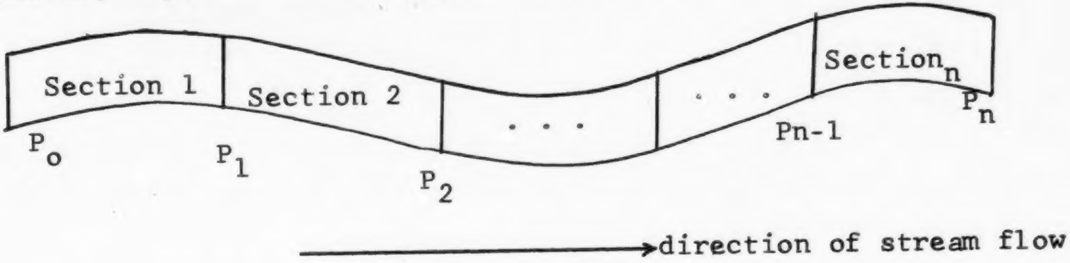
MODEL AND INPUT DATA:

The portion of the stream under study is partitioned into n sections, say, as in the diagram below:



The following information is needed as input to the computer. This information is assumed known from previous stream analysis. Any of this input information may be varied at will though, in order to obtain the oxygen profile under various conditions.

P_j = distance from point j to the mouth of the river (in arbitrary units), $o \le j \le n$.

T_j = temperature in ^oC at point j, $1 \le j \le n$.

V_j = volume between the points j-1 and j (in millions of gallons), for $1 \le j \le n$.

D_j = average depth in feet for the section included between the points j-1 and j, for $1 \le j \le n$.

Q_j = the runoff past the point j (in cfs), $1 \le j \le n$.

S_j = the "sludge" (in population equivalents) at the point j, $1 \le j \le n$.

ID_j = amount of chemicals, etc., which require an immediate supply of oxygen at the point j (in population equivalents), where $i \le j \le n$.

L_j = amount of oxygen-requiring waste material (in population equivalents) introduced at the point j which does not require oxygen immediately, $1 \leq j \leq n$.

In Summary:

$P_o \ldots P_n$	(milepoint)
$T_1 \ldots T_n$	(temperature)
$V_1 \ldots V_n$	(volume)
$D_1 \ldots D_n$	(depth)
$Q_1 \ldots Q_n$	(runoff)
$S_1 \ldots S_n$	(sludge)
$ID_1 \ldots ID_n$	(immediate demand)
$L_1 \ldots L_n$	(organic pollution load)

The following three quantities are also needed:

X = that percentage of the oxygen saturation value which is actually realized in the stream. Generally X is about 85%.

Y = initial waste load (in population equivalents) introduced at the initial point P_o on the stream, where the analysis begins.

k = the BOD rate of amortization. Generally k is between 0.1 and 1.5.
k must usually be determined empirically for each stream.

ALGORITHM FOR OBTAINING OXYGEN PROFILE:

The following set of equations is an algorithm for obtaining the amount of dissolved oxygen (expressed as a percentage of the saturation value) at each of the points $P_1 \ldots P_n$. It should be readily adaptable to most computers. To save storage space in the computer the input data is read into the computer for one point at a time. The resulting output data is printed for one point at a time. The program is as follows (items in parentheses are remarks);

```
START
READ    n, X, Y, k    (n = no. of points, X = normal value of per
                      cent oxygen saturation,
                      Y = initial waste load at $P_o$,
                      k = BOD amortization rate).
```

PCTSAT = X (PCTSAT is the per cent oxygen saturation, and is initially set at the value x).

SUMPAY = 0 (SUMPAY is the total amount of waste material amortized up to the point j).

SUMREO = 0 (SUMREO is the total amount of oxygen obtained from reoxygenation up to the point j).

THROUGH DONE, FOR j = 1, 1, j = n

(this is an iterative statement and it means: "do the following statements up to and including the statement labeled 'DONE', over and over again, with an initial value of j = 1, incrementing j by +1 each time the statement 'DONE' is reached, and halting the iterative process when 'DONE' is reached when j = n).

READ P, T, V, D, Q, S, ID, L

(the input data, as explained on pp. 1, 2, are read into the computer for the point j).

$$\text{TIME} = 1.547\,\frac{V}{Q}$$

(this is the time of passage from point j-1 to point j).

$$\text{SATOXY} = \begin{cases} 22.42 \cdot Q \cdot (14.62 + T(.00565(T - 10) - .329)) & \text{if } T < 20 \\ 22.42 \cdot Q \cdot (12.25 - .154T) & \text{if } 20 \leq T \leq 30 \\ 22.42 \cdot Q \cdot (10.6 - .1T) & \text{if } T > 30 \end{cases}$$

(this is the amount of oxygen at saturation)

$$\text{SUMRUN} = \frac{X \cdot \text{SATOXY}}{100}$$

(amount of oxygen the stream would normally attain).

$$\text{MIXMIN} = \begin{cases} 13.94\,(\log_e D) - 7.45 & \text{if } D > 3 \text{ ft.} \\ .721\,D + 2.279 & \text{if } D \leq 3 \text{ ft.} \end{cases}$$

(this is the "turnover time" for the stream).

NEXTY = Y · exp (-2.3026·k·TIME)

(amount of unamortized waste at j).

SUMPAY = SUMPAY + Y - NEXTY + S + ID

(total amount of waste amortized up to point j).

Y = NEXTY + L (this "resets" the waste load Y for the next iteration).

$$F = \frac{.486\sqrt{\text{MIXMIN}}}{D}\ \exp\,(.0745 \cdot T - .7738).$$

(F is an intermediate variable in the calculation of REO, which will be explained later).

$$R = 1 + \frac{.0896\ MIXMIN \cdot Q}{F \cdot V}$$

(R is another intermediate variable).

$$NETOXY = SUMRUN + SUMREO - SUMPAY$$

(this is the total amount of oxygen at the point j except for the oxygen obtained by reoxygenation).

$$REO = \frac{SATOXY\ (2 - .01\ PCTSAT) - NETOXY - ID}{R}$$

(this is the amount of oxygen gained by reoxygenation between the points j-1 and j. The PCTSAT on the right hand side is from the previous iteration and refers to the point j-1).

$$PCTSAT = \frac{100}{SATOXY}\ (NETOXY + ID + REO)$$

(this is the dissolved oxygen as a percentage of the saturation value. When ID = 0 the PCTSAT just calculated is correct as is. When ID ≠ 0 the PCTSAT just calculated is the same as if ID had been zero. When ID ≠ 0 the following three expressions [labeled (1), (2), (3)] are executed. If ID = 0 they are merely skipped over).

(1) $REO = REO + \frac{ID}{R}$

(this is the true REO when ID ≠ 0).

(2) $IDPCT = \frac{100}{SATOXY}\ (NETOXY + REO)$.

(this is the true PCTSAT when ID ≠ 0).

(3) PRINT RESULTS IDPCT

(instruct the computer to print IDPCT when ID ≠ 0).

$$SUMREO = SUMREO + REO$$

(resets SUMREO for the next iteration).

DONE PRINT RESULTS j, P, PCTSAT

(now go back to the iterative statement and repeat for the point j + 1).

END OF PROGRAM